The Journal of Bone and Joint Surgery

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The American Orthopaedic Association
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The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association
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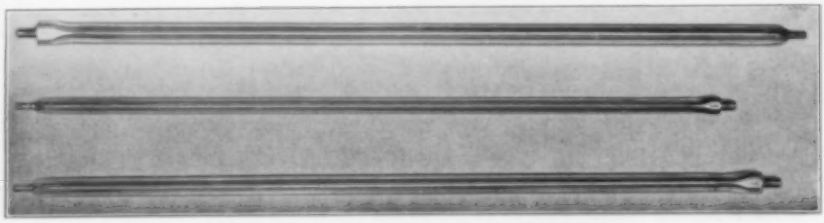

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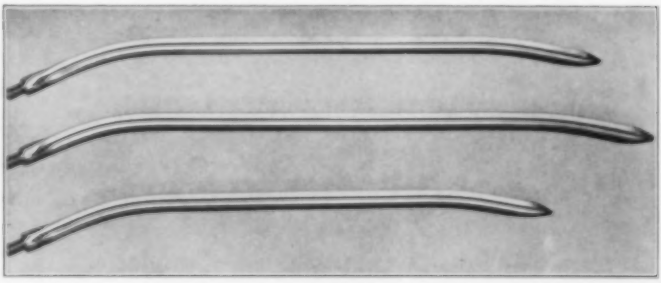

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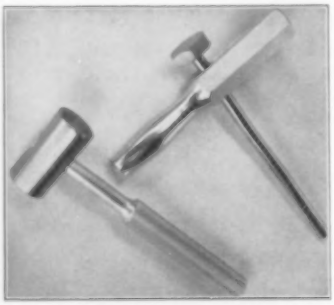

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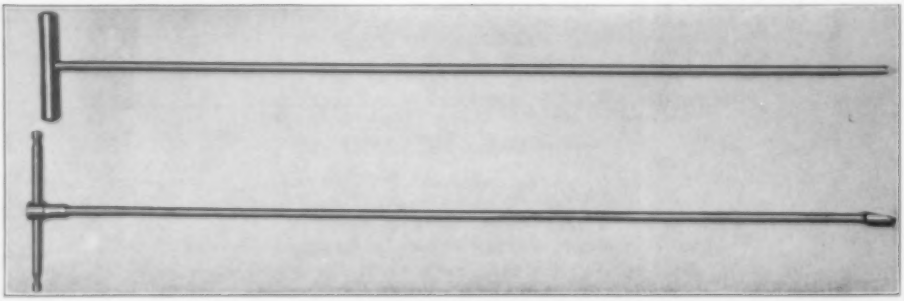

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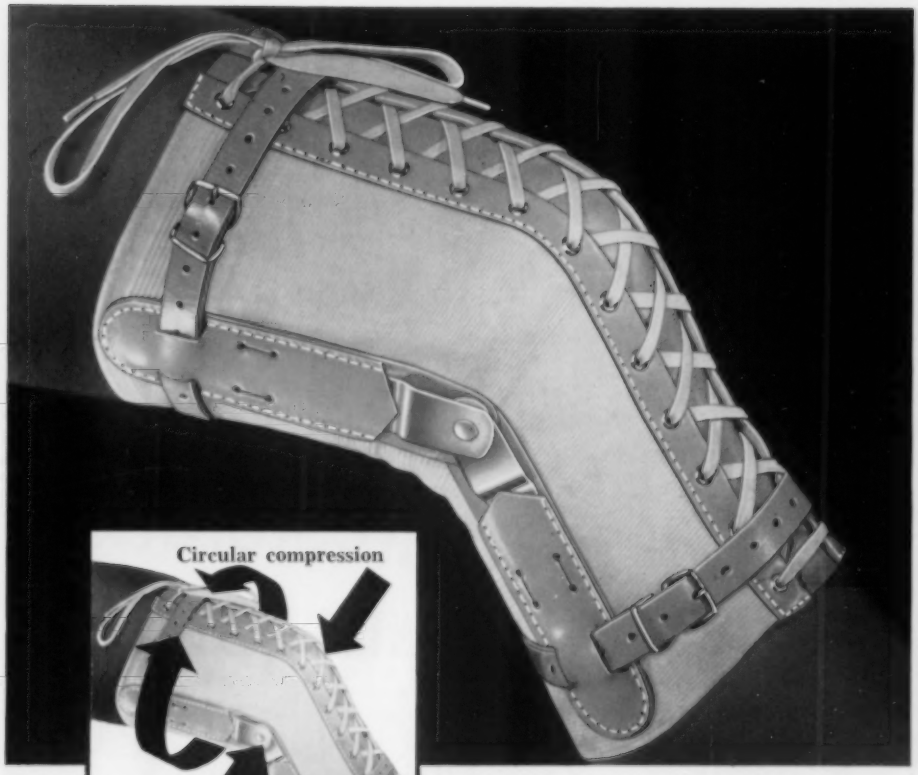

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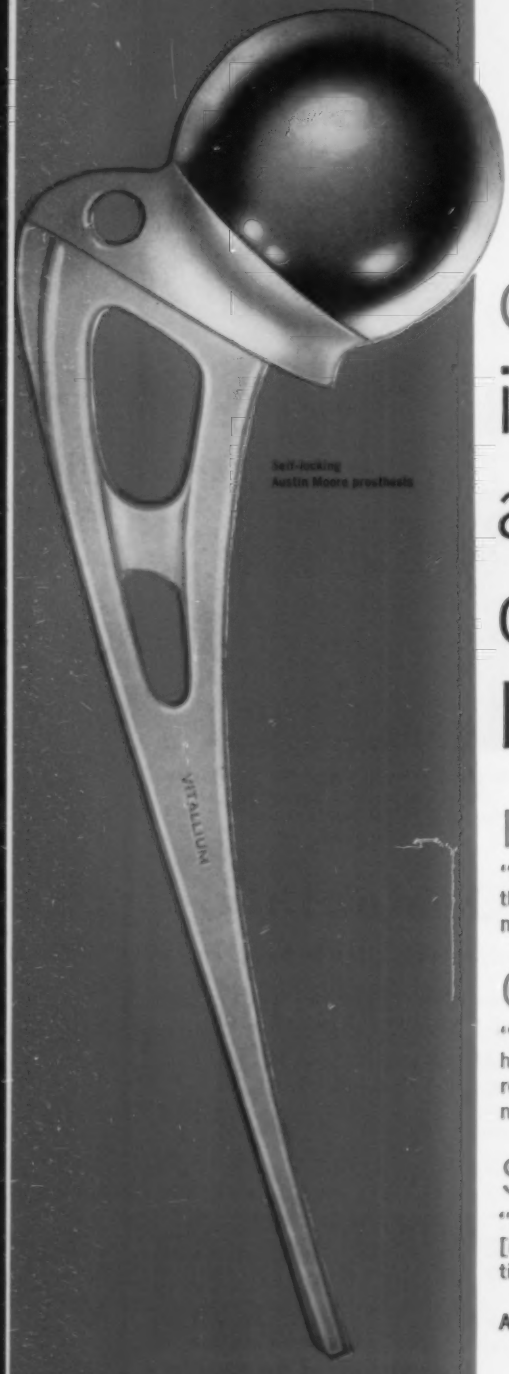

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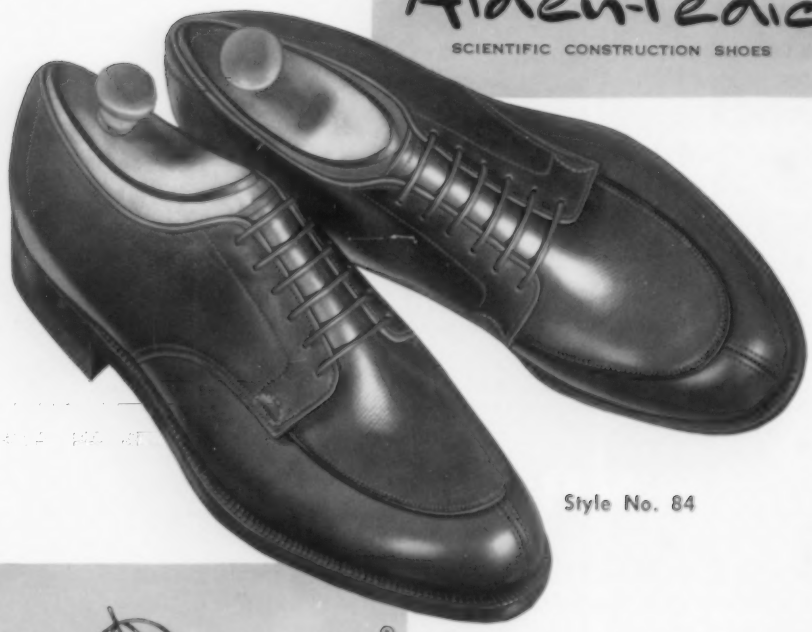

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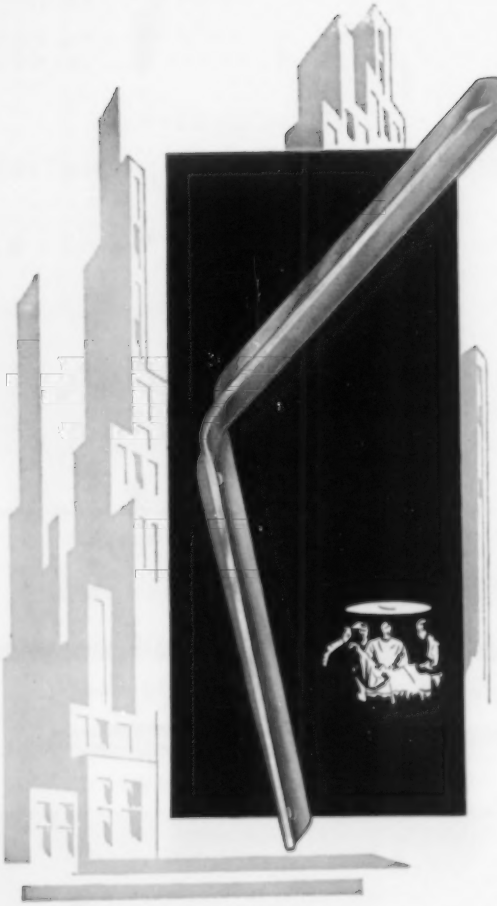

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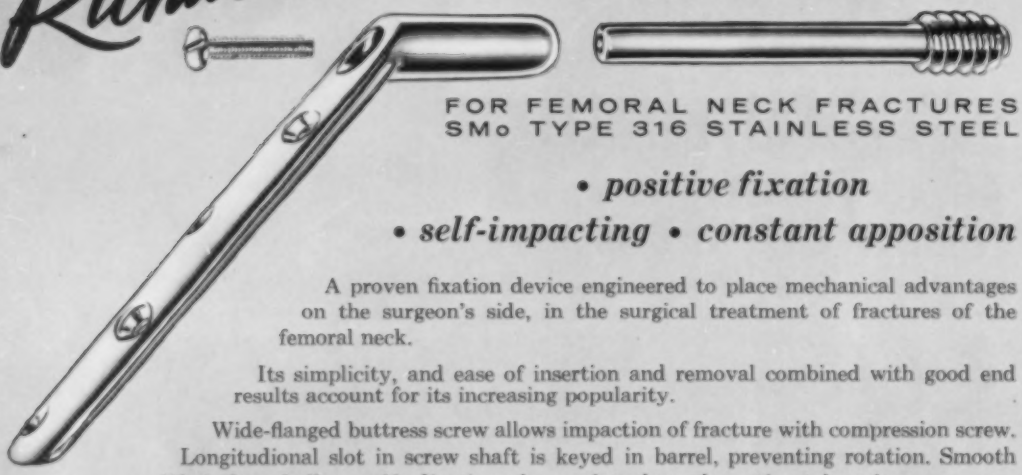

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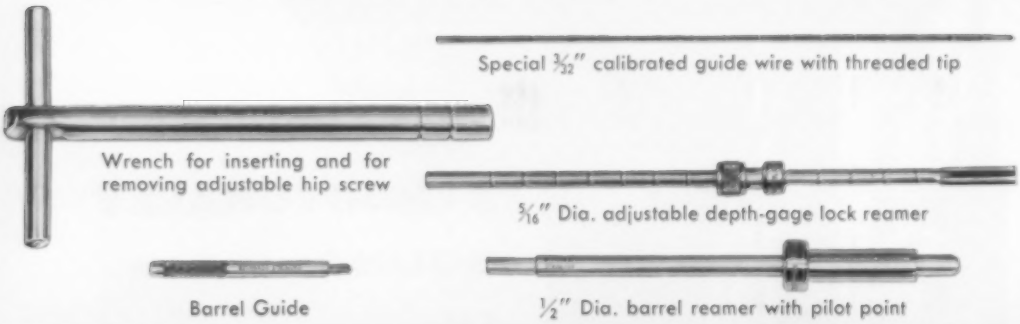

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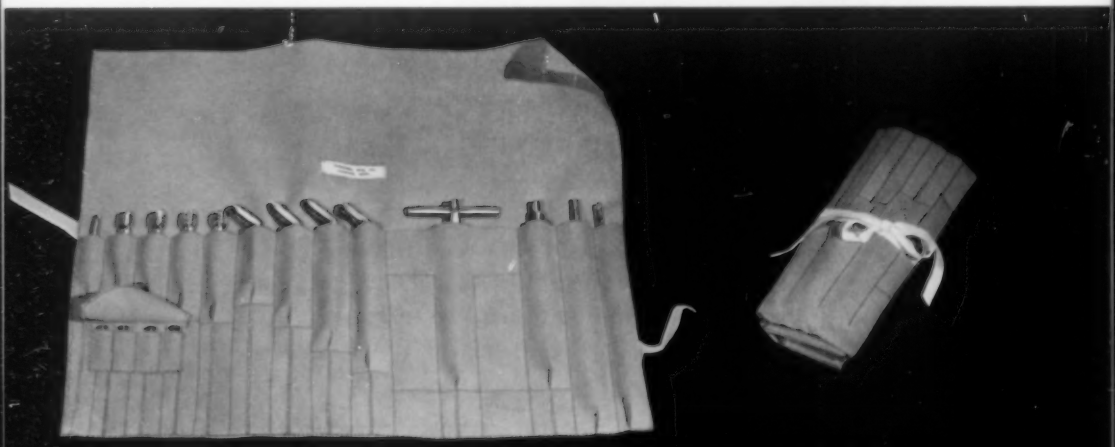

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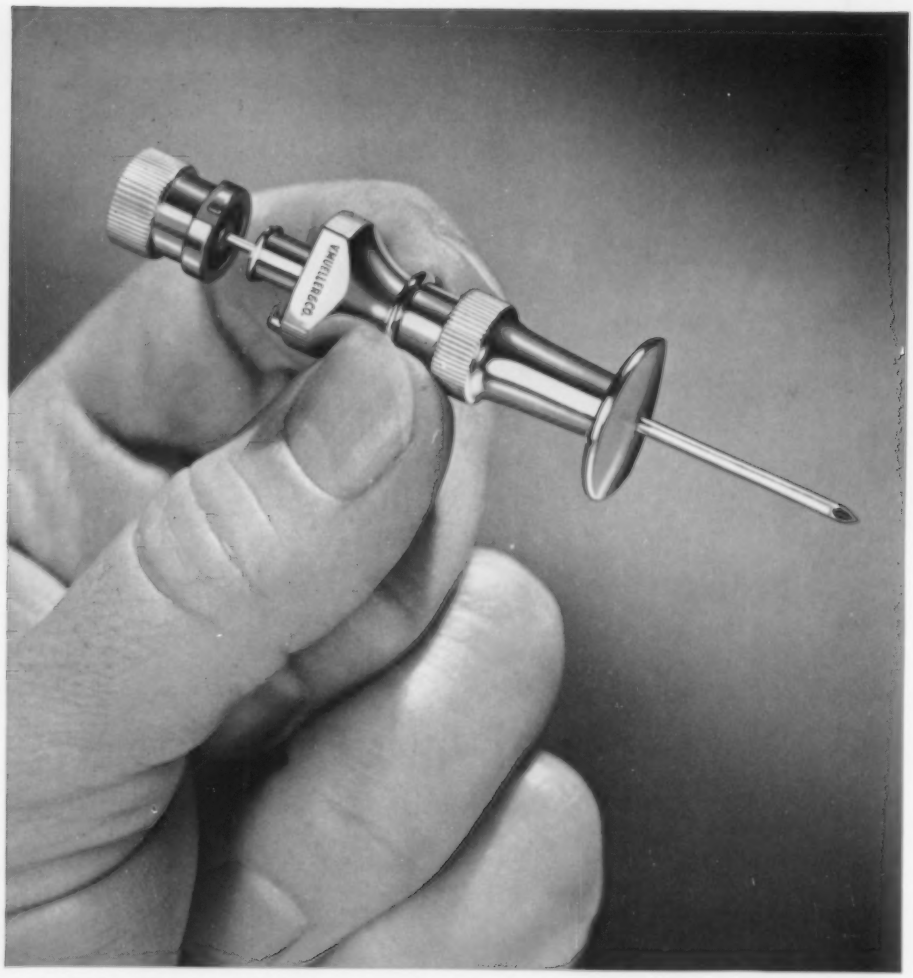

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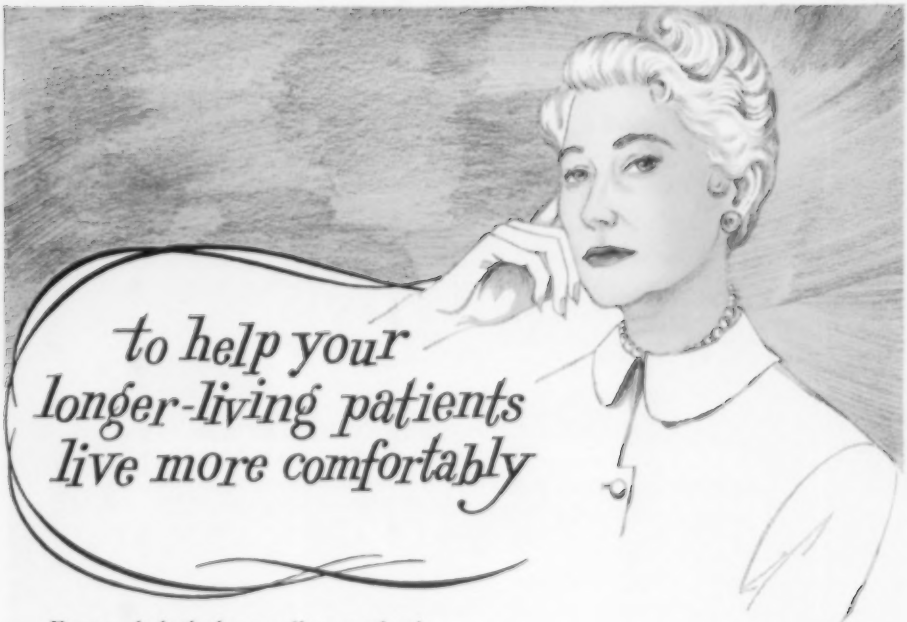

to help your longer-living patients live more comfortably

For psychological, as well as mechanical reasons, a Spencer Support individually designed to meet the needs of your geriatric patient can contribute a great deal to peace of mind and physical comfort. With relaxed abdominal muscles properly supported and body balance improved, male or female experiences a physical lift — is less likely to be plagued by chronic fatigue. Whether you prescribe a Spencer primarily to improve posture or for another specific condition, the Spencer Corsetiere takes exacting measurements of the *controlled* body — to ensure that the individually designed support will do precisely what you want it to do — to aid in your treatment.

Spencer Supports — for abdomen, back or breasts — are available only through a Spencer Corsetiere or Spencer Support Shop. When immediate support is required, the Corsetiere offers the patient an emergency support to wear while awaiting delivery of the individually designed Spencer.

Spencer's Individual Designing Service is available to you through Corsetieres specially trained to help you help your patients.

SPENCER®

individually designed supports for women, men and children

SPENCER, INCORPORATED
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☐ Send me the name of the nearest Spencer Corsetiere.

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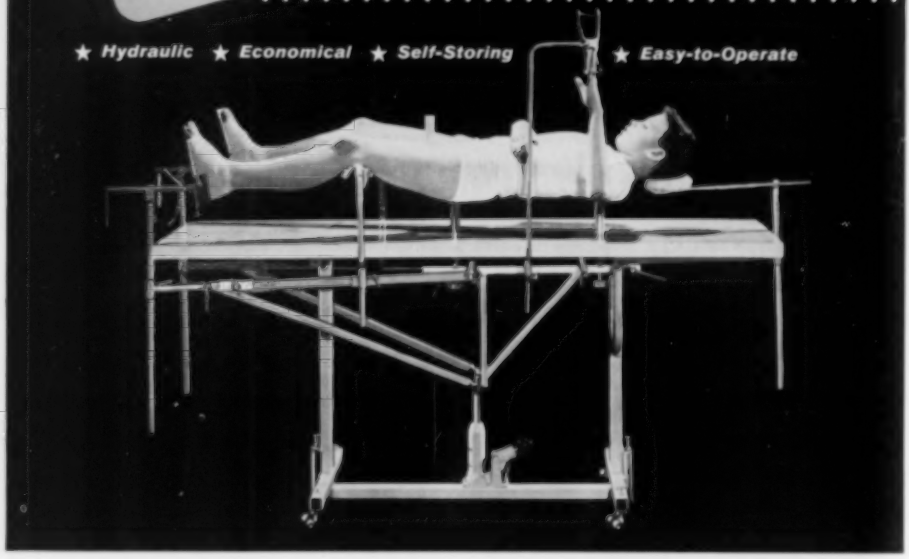
7-61

The NEW All-Purpose . . .

Stryker

CAST TABLE

★ Hydraulic ★ Economical ★ Self-Storing ★ Easy-to-Operate



Now! A table designed specifically for all types of cast applications – body jackets, hip spicas, long and short leg casts, scoliosis casts, arm casts of all kinds. This economical, easy to set-up table simplifies plaster work, too. After positioning, the patient is hydraulically lifted for easy access to all body areas.

Padded top, adjustable knee holder rods and head rest make the table comfortable even for unanesthetized patients. Basic accessories store in position underneath. And when not used for cast applications, the Stryker Cast Table serves as an examining table. Write for full information or ask your dealer for a demonstration of the new Stryker Cast Table. You'll like its low cost, as well as its many advantages.

PLUS THESE EXCLUSIVE EXTRAS:

Heel and sole plate separate and pull out, after plaster is wrapped around foot. Leg and knee, in place, can be moved laterally as required.

Simplified toe and finger clamps hold the extremity for you with no more pressure than you would hold it yourself.

Floor stops stabilize the table, prevent movement.

Sacral and shoulder plate knobs secure and release the plates from below.

Unit cost $690.00

Stryker

SURGICAL AND HOSPITAL EQUIPMENT

Orthopedic Frame Company

420 ALCOTT STREET • KALAMAZOO, MICHIGAN

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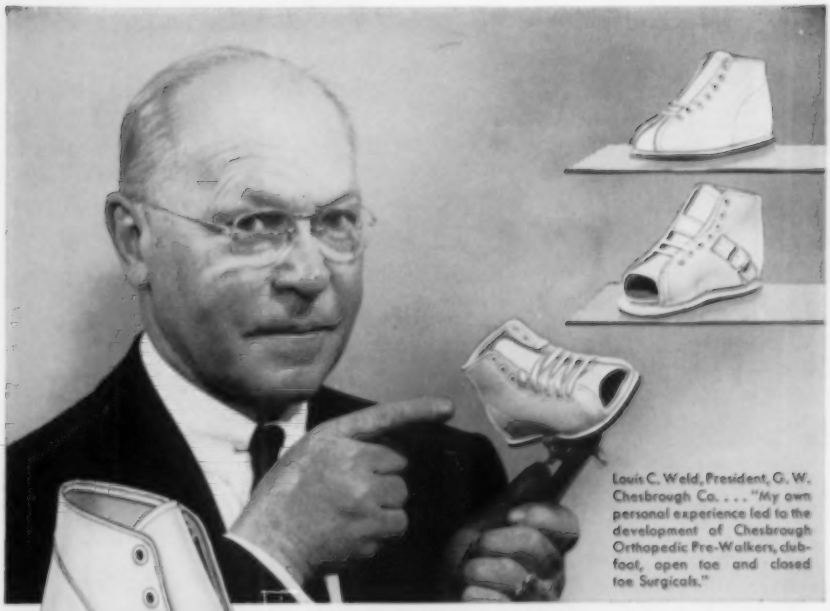

Louis C. Weld, President, G. W. Chesbrough Co. . . . "My own personal experience led to the development of Chesbrough Orthopedic Pre-Walkers, club-foot, open toe and closed toe Surgicals."

"Orthopedic shoes parents can afford . . .

CHESBROUGH Corrective Pre-Walkers"

"When a child in my own family needed a corrective shoe, I discovered what a strain it can mean to a family budget, because 1) corrective footwear is expensive and 2) frequent purchase of new corrective shoes is required. Then and there I decided there was a real need for a moderately priced corrective shoe —a shoe parents could afford. That's why and when Chesbrough Orthopedic Pre-Walkers were born.

"Our 60 years of shoe-making experience resulted in corrective Pre-Walkers of scientific design, expert workmanship, fine leathers combined with orthopedically correct lasts to provide necessary correction at an economical price."

Today—just three years later—orthopedic specialists in 45 states and several foreign countries are prescribing these shoes.

All shoes in unlined white elk, sizes 000 to 4, narrow and wide. Available in full pairs, split pairs or single shoes (no extra charge for half pairs).

No. 1400 OPEN TOE. Straight-line symmetrical last, firm heel, no back seam. Adaptable to Denis Browne Splints.

No. 1700 CLUBFOOT, OPEN TOE. Special outflare last, sturdy instep strap to stabilize heel.

No. 1300 CLOSED TOE. Lace-to-toe design permits snug, gentle fit. Perfectly smooth inside.

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YOUR ORTHOPEDIC SHOE DEALER:

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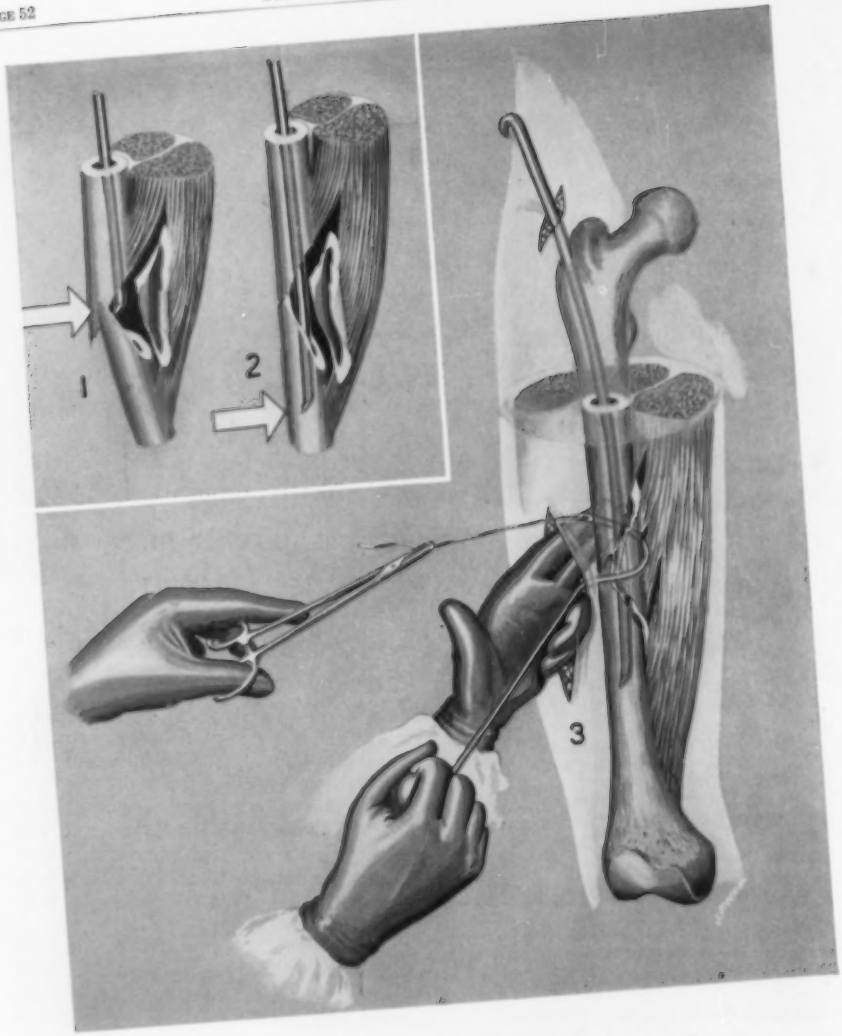
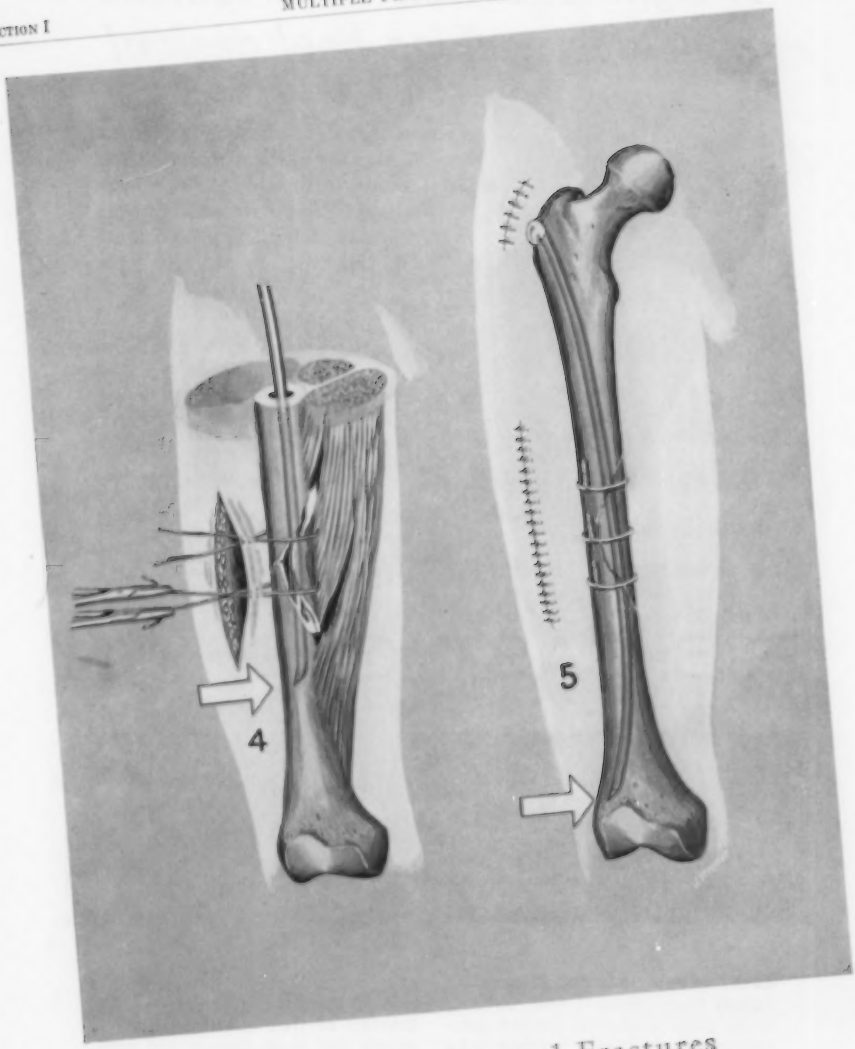


Technic Comminuted Fractures

(1) Drive the pin to fracture site.

(2) Align proximal and distal fragments, engage pin in distal fragment, but do not drive pin home.

(3) Leave soft tissue attached to fragments. Pass wire-carrier close to bone, through the muscle attachment using the guiding fingers. Thread point of wire carrier to place wire loop around the bone.



Technic Comminuted Fractures

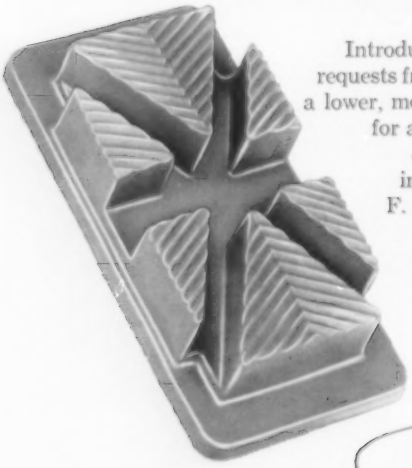
(CONTINUED)

(4) Use wire loops instead of bone clamps to maneuver fragment or fragments into position. Twist wire snugly but not tight.

(5) Drive pin home, tighten wires to complete operation.

THE BERIVON Company
Meridian, Miss.
MANUFACTURERS RUSH PINS AND INSTRUMENTS • PUBLISHERS ATLAS OF RUSH PIN TECHNICS

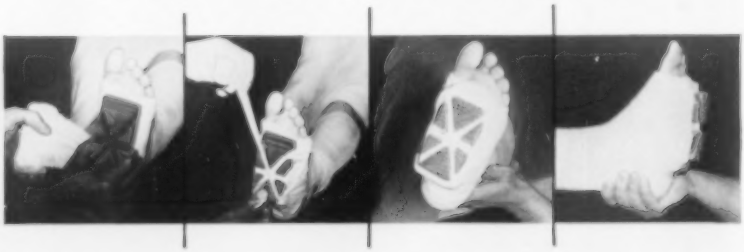
A significant new development in walking heel design!



Introduced in response to numerous requests from the medical profession for a lower, more comfortable walking heel for ambulatory cast patients, and one which could be anchored in the cast more securely. The F. B. CAST CUSHION is the result of extensive research, experimentation and clinical testing and brings you these many long awaited advantages.

De Puy

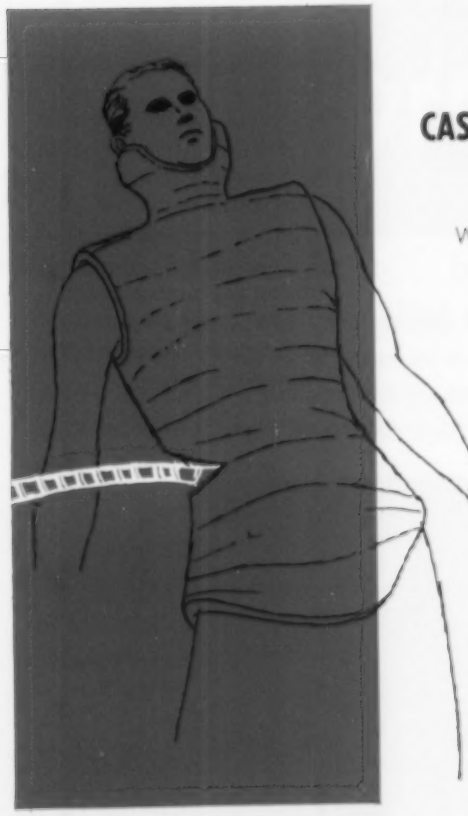
F. B. CAST CUSHION



Easier to apply and anchor more securely than conventional walking heels. Deep criss-cross section spacing permits the plaster bandage to be applied as a normal figure eight wrapping as illustrated. Raised tips on inner side of CAST CUSHION set firmly in cast to prevent lateral movement.
Lower for greater patient comfort and elimination of forced limp...a true walking aid, not a stilt.
Molded of fine quality rubber... strong and long wearing, yet sufficiently resilient to provide adequate cushioning and shock absorption. No-slip, no-mar tread.
Order a supply today...No. 845, $15.00 per dozen.

DePuy Manufacturing Co., Inc., Warsaw, Indiana

PATIENT aire



for under CAST VENTILATION

We are proud to introduce PATIENT-AIRE, another product of Conco's research into modern materials for modern medicine.

- *reduces itching*
- *prolongs cast life*
- *dries cast*
- *diminishes odor*
- *avoids ulceration*
- *cools under cast*
- *warms under cast*
- *X-ray permeable*

CONCO
SURGICAL PRODUCTS, INC.

RESEARCH • DEVELOPMENT • PRODUCTS
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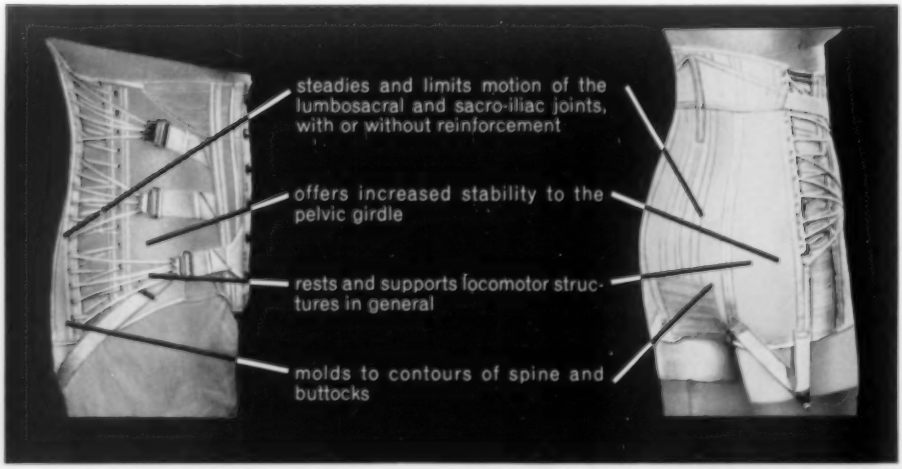
CAMP

LUMBO-SACRAL SUPPORTS

helpful in treatment of injuries, postural or occupational strain and certain other diseased conditions of the low back

Camp orthopedic supports for men and women play an important part in the conservative treatment of one of the most vulnerable portions of the spine—the lumbosacral joint. These supports are scientifically designed to give a secure fit to the pelvic girdle, the upper lumbar and low dorsal spine, including the entire abdomen in front, thus giving maximum lumbar spine support with greatest patient comfort. By curving in and under the gluteal region, the garment is anchored and tension on these muscles and their attachments is relieved. Supports are firmly boned in the back and may be reinforced with pliable steels, Camp spinal brace, or a Cook Shingle. In addition any lumbosacral support with the new Camp Dorso Taylor insert may be easily converted into support for the dorso spine.


steadies and limits motion of the lumbosacral and sacro-iliac joints, with or without reinforcement
offers increased stability to the pelvic girdle
rests and supports locomotor structures in general
molds to contours of spine and buttocks

S. H. Camp & Company, Jackson, Michigan

S. H. Camp & Company of Canada, Ltd., Trenton, Ontario

CAMP

The first step to proper fit

Most doctors agree that recommending Child Life Shoes is the first step to the best fit possible. Child Life are designed to fit better . . . built to keep their shape and fit until the child outgrows the shoe.

When suggesting Baby's first shoes or writing a shoe prescription for a youngster with a foot problem, remember Child Life Shoes and their competently trained shoe fitters can fit every type of foot.

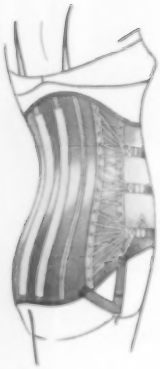
Child Life
SHOES

MERIT YOUR PROFESSIONAL RECOMMENDATION

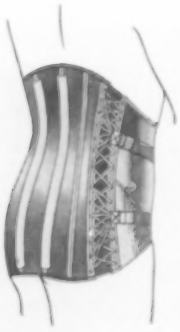
HERBST SHOE MANUFACTURING CO., Box 2005, Milwaukee 1, Wisconsin

FOR
ORTHOPEDIC
APPLICATIONS

Freeman SURGICAL SUPPORTS



MODEL 423
Sacro-Lumbar Back
Support for Women



MODEL 422
Sacro-Lumbar Back
Support For Men

For 68 years Freeman has worked closely with orthopedic surgeons to design surgical garments that provide *correct* support. Each garment is made by skilled craftsmen using the finest materials available.

There's a quality Freeman support for most every application. You can be certain that the garment you select will carry out your prescription to the best possible satisfaction of you and your patient.

Freeman corset-type back supports provide bracing in any desired degree to almost complete immobilization. Special construction features assure comfort for the wearer in sitting, standing and reclining positions.

FREEMAN QUALITY FEATURES

New Dacron-Pima Cotton Fabric. Petal-Soft Interior Finish cushions the stays, avoids irritation. Self-Smoothing, Exclusive Non-Wrinkle Fly speeds putting on garment and avoids comfort-robbing wrinkles. Soft Plush Padding under hooks and eyes. Superb Needle Work.

Prescribe **FREEMAN** *with Confidence!*

Write over your letterhead for
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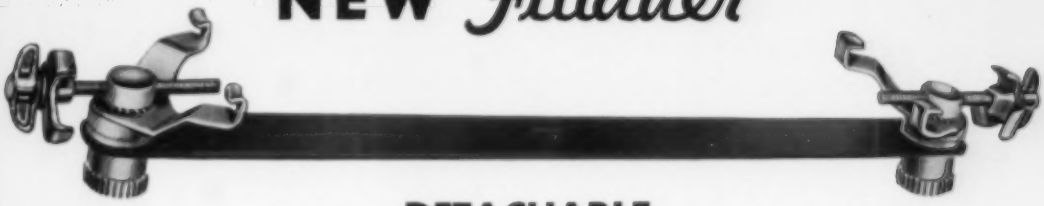
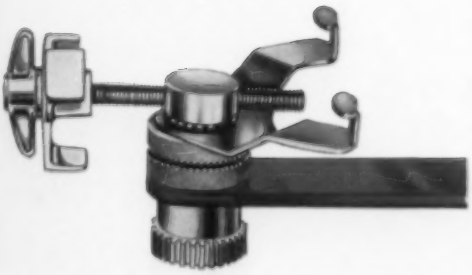
FREEMAN MANUFACTURING COMPANY
Dept. 707, Sturgis, Michigan

NEW Fillauer



DETACHABLE

DENIS BROWNE NIGHT SPLINT



STREAMLINED and IMPROVED

1. Precision die cast Serrated Discs permit 50 positions.
2. New Knurled Screw locks discs in position.
3. New Triple Flange fits club foot shoes or any sole thickness.
4. Streamlined Wing Screw secures flange to shoe sole.
5. Durable, attractive red alumilite color on bars.
6. Lengths 6, 7, 8, 9, 10, 12, 14, 16 and 18 inches. Special lengths to 30 inches at no extra cost.

ORTHOPEDIC SURGEONS recognize the decided advancements this versatile splint affords in treating club feet, positional deformities, tibial torsions, flat feet and congenital hip dislocations. Also applicable for any other deformities that are actively corrected by incessant kicking.

Very little adjustment by surgeon or orthotist is required to fit and position this new Fillauer Detachable Splint.

Pre-walker or larger surgical and club foot shoes work extremely well with the Fillauer Splint. Outgrown shoes may be used by cutting out toes.

Fillauer SURGICAL SUPPLIES, INC.
BOX 1678 CHATTANOOGA, TENN.
ESTABLISHED 1914 *Manufacturers of Orthopedic Supplies*

Put your low-back patient back on the payroll

Soma relieves stiffness –stops pain, too

YOUR CONCERN: Rapid relief from pain for your patient. Get him back to his normal activity, *fast!*

HOW SOMA HELPS: Soma provides direct pain relief while it relaxes muscle spasm.

YOUR RESULTS: With pain relieved, stiffness gone, your patient is soon restored to full activity—often in days instead of weeks.

Kestler reports in controlled study: *Average time for restoring patients to full activity: with Soma, 11.5 days; without Soma, 41 days.* (*J.A.M.A. Vol. 172, No. 18, April 30, 1960.*)

Soma is notably safe. Side effects are rare. Drowsiness may occur, but usually only in higher dosages. Soma is available in 350 mg. tablets. **USUAL DOSAGE:** 1 **TABLET Q.I.D.**

The muscle relaxant with an independent pain-relieving action

SOMA®

(*carisoprodol, Wallace*)

Wallace Laboratories, Cranbury, New Jersey

CRAWFORD-ADAMS CONCENTRIC HIP ARTHROPLASTY*

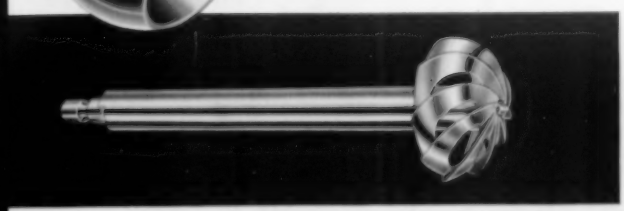
*Full details of this technique were published in THE JOURNAL OF BONE & JOINT SURGERY, British Volume, May, 1953.

Available only in

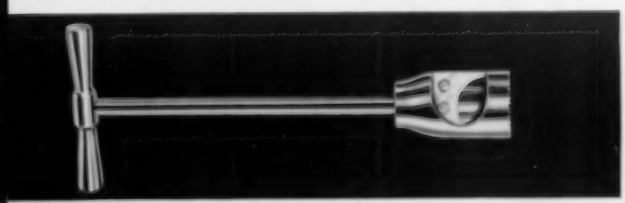
SMo AISI 316

. . . the metal of established superiority for internal fixation appliances. SMo stainless steel has borne the test of time commendably in the field of surgical implants . . . for strength . . . for corrosion-resistance . . . for compatibility . . . Versatile because it is wrought . . . *chosen by more surgeons than all other metals combined.*

Femoral Head—No. 701—Standard size meets 95% of all requirements. Extra large and extra small sizes are available.



Duthie Reamer—No. 514—The open nature of the cutting blades makes clogging impossible. Hand sharpened to ensure maximum cutting. Assures precision fit of concentric femoral head in the acetabulum.



Femoral Neck Shaper and Reamer—No. 164—Designed to ream the femoral head and neck in one operation to the exact contour of the concentric cup. No. 164, Universal Size; No. 164B, Small Size.

note snug fit . . .

of the moving parts which ensures concentric movement and widely distributed weight-bearing contact. Clearance is sufficient to allow the formation of lining membranes upon the acetabular and femoral surfaces.

Available through your surgical supply dealer.

OEC® Our Sign of Quality

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WRIGHT ANGULAR BONE CLAMP FOR SMALL BONES

No. 644 — Length: 5 3/4", jaws: 3/4" x 1/4", Stainless.
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the hand

No. 454 — HOKE OSTEOTOMES — straight or curved, widths: 1/8", 3/16", ¼", 5/16", 3/8", ½", Stainless.
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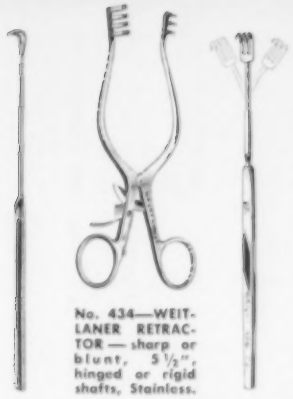

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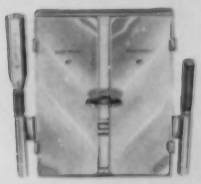
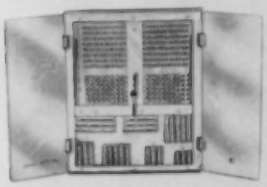
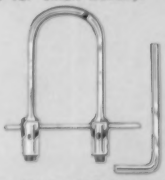
No. 651 — GOODFELLOW RETRACTOR — 8¼", 2 prongs, Stainless.

No. 444—FLEXIBLE RETRACTOR —2 or 3 prongs, sharp or blunt, chrome Handle.





No. 675 — CORBETT SCREW AND PLATE RACK—Stainless, includes: 25 dozen Smo Stainless Steel assorted screws, 28 Smo Stainless Steel assorted plates, 2 Stainless Steel screw drivers—1 with holding shield. (Designed for small bones).



No. 298—FINGER TRACTION BOW—depth: 2", 3", or 4", width: 1", Stainless.

No. 692—T FINGER SPLINT—Aluminum.

No. 627 — HAND DRILL — —5/32" chuck capacity, Anodized Aluminum Handle.

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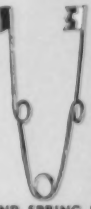
No. 197—SET OF 13 RUSH MEDULLARY PINS AND RACK — 3/32" diameter, length: 1" through 4" graduated in 1/8" increments, Smo Stainless Steel.



No. 443—HAND SPRING RETRACTOR —self retaining, 3½", 4½" or 7", Stainless.

No. 636 — RYERSON TENOTOMES —set of 5 styles, Stainless.

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ALL WRIGHT MANUFACTURING COMPANY PRODUCTS ARE PRECISION MADE AND UNCONDITIONALLY GUARANTEED AGAINST DEFECTIVE WORKMANSHIP. MANY OF THE FINEST INSTRUMENTS USED BY ORTHOPEADIC SURGEONS TODAY WERE ENVISIONED BY THE HIGHLY SKILLED ARTISANS OF WRIGHT MANUFACTURING CO. WE PLEDGE OUR CONTINUED DEDICATION TO THE HIGHEST OF STANDARDS IN PRODUCTS AND SERVICE.

Wright Manufacturing Company

880-882 ADAMS AVENUE MEMPHIS, TENNESSEE

"... he runs and plays again!"

Hanger Prosthetic Appliances have brightened the present and the future for many amputees. For example, Weaver Nolt says: "My son, Lloyd, was a pathetic figure in a big hospital bed after his legs were amputated because of an accident. Today it's a big and wonderful world again as he gets along so wonderfully on his Hanger Legs. He walks without any help, and runs and pushes his wagon all over the farm. That other day is just a hazy memory and we are so pleased things are so different than we expected."

Hanger PROSTHETICS

AVAILABLE AT AUTHORIZED FACILITIES IN THE FOLLOWING CITIES:

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ROANOKE 12, VA.
WASHINGTON 13, D. C.

Central Region:

COLUMBUS 8, OHIO
PITTSBURGH 1, PA.

Southeastern Region:

ATLANTA 9, GA.
BIRMINGHAM 1, ALA.
COLUMBIA 1, S. C.
JACKSONVILLE, FLA.
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CINCINNATI 29, OHIO
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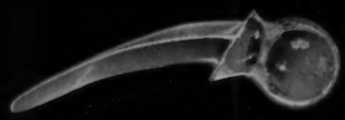
FEMORAL PROSTHESES

(SMo STAINLESS)

for every requirement

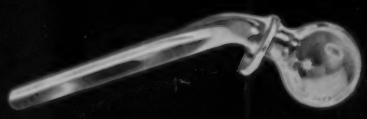
Richards Femoral Prostheses are solid forged, precision machined of SMo stainless, electropolished for optimum tissue tolerance. Offer maximum ductility, maximum strength, mirror finish and hollow concentric head for reduced weight. These popular forms available with specially designed rasps and broach to facilitate insertion. Teflon faced drivehead assures against damage to polished, precision head, producing smooth motion against the acetabulum, precludes possible contamination to surface of prosthesis head. Packaged in Kane Sterifabric Sterilizing Case.

Write For Full Information

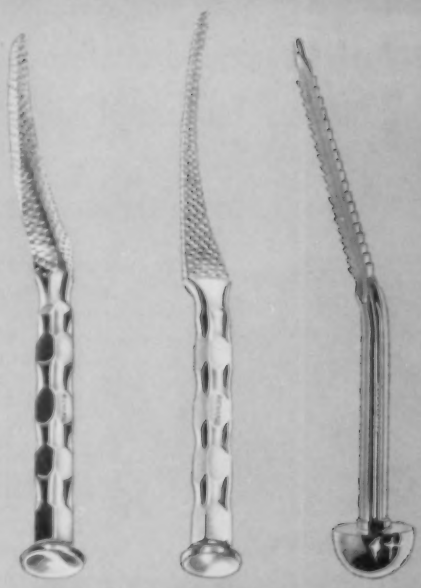


F. R. Thompson Type Hip Prosthesis — Popular choice of surgeons because of its ease of insertion and good results.

Moore Type Hip Prosthesis — Holes in stem allow bone growth through the prosthesis (sometimes filled with bone crumbs before insertion).



Eicher Type Hip Prosthesis — Tri-finned shaft, available in two diameters. Shaft length 5½".



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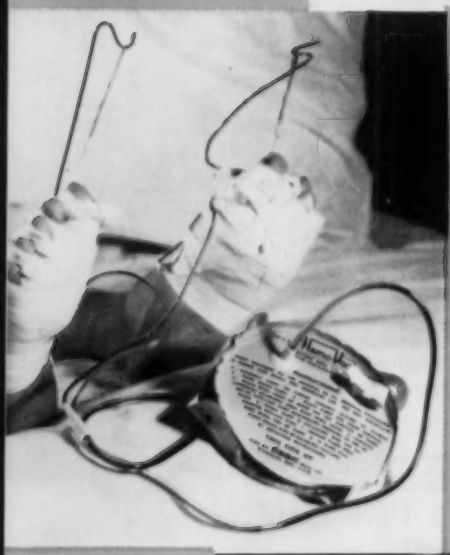

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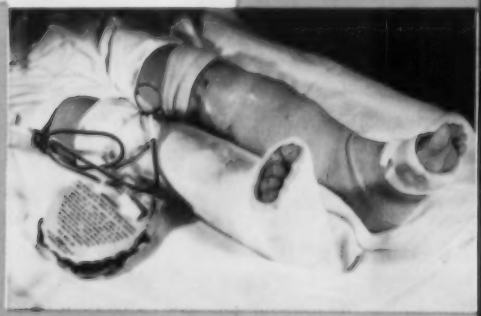

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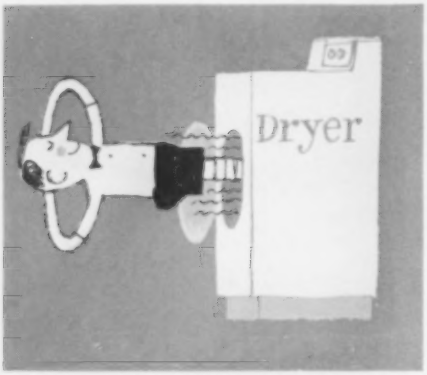

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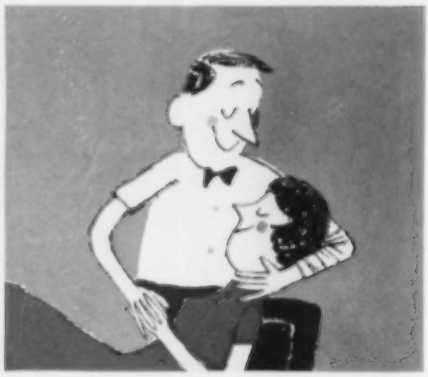

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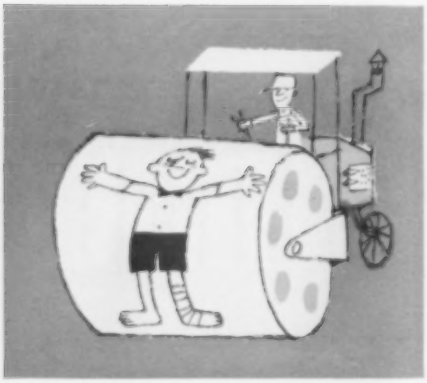

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American Volume

Amputation and Prosthesis as Definitive Treatment in Congenital Absence of the Fibula*

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From the Shriners' Hospital for Crippled Children, Springfield

The fibula was reported by Coventry and Johnson to be the most frequent congenitally absent long bone. This observation was also made by O'Rahilly, who tabulated the reported cases of absence of the long bones. He found 296 cases of absent fibula in the literature prior to 1935 and observed that after the fibula, in descending order of frequency, the radius, femur, tibia, ulna, and humerus were congenitally absent.

The findings of these authors paralleled our experience at the Shriners' Hospital for Crippled Children. Since the hospital opened in 1925, sixty-two instances of absent fibula were noted in forty-eight patients. Reviewing the records of these patients, we found that prior to 1950, only five patients were treated by amputation, whereas subsequent to 1950, twenty children with this anomaly were treated by amputation and a prosthesis, and two other children were fitted with prostheses without amputation of the deformed extremity.

It is the purpose of this paper to present our experience with the treatment of congenital absence of the fibula.

ETIOLOGY

As in most congenital anomalies, the etiology remains unknown, although whatever it is, the etiological factor must act prior to the sixth or seventh week of embryological development, since it is at this time that the anlage of the long bones is formed. Although some skeletal anomalies appear to be hereditary, there is no evidence that heredity plays any role in this deformity. It is of some interest that one patient in this series with bilateral hypoplastic femora and unilateral absent fibula has married and given birth to a normal child.

Congenital absence of the fibula has been well described and its treatment discussed by many authors. In 1952, Coventry and Johnson presented twenty-nine cases, of which twenty-two were unilateral and seven bilateral. Treatment was of the so-called conservative type; amputation was performed on only two

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Miami Beach, Florida, January 13, 1961.

patients, whereas three of the patients mentioned were still wearing a built-up shoe and one was wearing a brace at the time of writing.

In 1957, Thompson and Straub presented a series of thirty-one congenitally absent fibulae in twenty-five patients. Amputation was mentioned as being done only as a last resort. However, the tabulated results revealed leg-length discrepancies varying from three and one-half to five and one-half inches and in the instances mentioned, the patients were still using braces or built-up shoes. Aitken presented ten patients with congenital absence of the fibula, eight with unilateral and two with bilateral involvement, all of whom were treated by amputation and prostheses. The primary difficulty in these patients was leg-length discrepancy. Farmer and Laurin presented a series of thirty-two instances of absence of the fibula in twenty-four patients. These authors also stressed leg-length discrepancy and favored early amputation if it seemed likely that shortening would amount to more than three inches.

TABLE I

SHRINERS' HOSPITAL SERIES

Forty-eight Patients (Sixty-two Absent Fibulae)

Classification	No. of Patients	Sex of Patients		Side Involved	No. of Absent Fibulae
		Male	Female		
Type I	1	1		Left, 1	1
Type II	28	16	12	Right, 19	28
unilateral				Left, 9	
Type III					
bilateral	14	10	4		28
unilateral	5	4	1	Right, 4	5
with anomalies				Left, 1	

PRESENT SERIES

The present series included sixty-two instances of congenital absence of the fibula occurring in forty-eight patients (Table I). Using the classification of Coventry and Johnson, we had one patient, a boy, in Type I (partial unilateral absence of the fibula with minimum length discrepancy), twenty-eight patients in Type II (complete or almost complete unilateral absence of the fibula, anterior bowing of the tibia, and equinovalgus of the foot), and nineteen patients in Type III (bilateral absence of the fibula in fourteen patients and unilateral absence accompanied by anomalies elsewhere in five patients).

The sex incidence usually reported is predominantly male in a ratio of two to one. In our Type II group, there were sixteen boys and twelve girls, whereas in Type III, there were fourteen boys and five girls. In the patients with unilateral involvement, the right side was affected approximately twice as often, there having been nineteen right and nine left fibulae absent. The clinical picture in the sixty-two instances followed very closely the general clinical picture usually described—not simply the absence of a long bone, but actual involvement of an entire limb. All had total absence of the fibula except the one patient classified as Type I. Sixty of the limbs had equinovalgus deformity of the foot (Fig. 1). Two had varus deformity of the foot when first seen (Fig. 9-A). All patients had anteromedial bowing of the tibia, although in some it was relatively slight.

Tarsal anomalies were present in most patients, but in some of the hospital records, the presence or absence of tarsal anomalies was not specifically mentioned. Cutaneous dimpling was not mentioned in all records and therefore was not tabulated.

Leg-length discrepancy appeared to be the major problem in the clinical picture of the patients in Type II. It is on this point that we shall dwell in this report. Our records show that an eventual length discrepancy of three inches occurred in all patients with complete unilateral absence of the fibula, except for one patient, now seven and one-half years of age, with a discrepancy of two and one-quarter inches, and three children who had amputations prior to attaining this degree of discrepancy. When associated hypoplasia of the femur is present, the discrepancy will be increased proportionately. It should be pointed out that in our series all patients with five metatarsal rays had shortening of the femur on the affected side, whereas this was noted in only 50 per cent of the patients with but three metatarsal rays.

Absent rays were tabulated in the patients with unilateral involvement in an effort to correlate this anomaly with length discrepancy (Chart I). It was noted that twelve children had three rays, eight had four rays, and eight had five rays. Leg-length discrepancy was plotted against age and it was found that in children with only three rays a discrepancy of three inches was reached at an average age of about six and one-half years. In children with four rays, the same three-inch discrepancy was reached at an average age of approximately four years; and in those with five rays, the three-inch discrepancy was reached at an average age of two years. This suggests an inverse relationship between leg-length discrepancy and absence of metatarsal rays.

Severe valgus feet in a patient with bilateral congenital absence of the fibula. Weight-bearing is almost on the medial malleoli.

FIG. 1

PAST TREATMENT

In reviewing our early cases, we found that conservative measures were the rule for initial treatment. The foot deformity was attacked by serial wedging plaster casts and by manipulation. These patients then used braces for maintenance of correction and equalization of leg-length discrepancy. When this more conservative type of treatment failed and recurrent deformity was observed, soft-tissue releases were carried out. During 1950 and 1951, following the teaching of Thompson and his associates, excision of the lateral band was carried out on six extremities in five patients, with some degree of correction obtained in all. Three of the patients eventually had amputation. The only child with a satisfactory result in this group (Case 6) had a one-inch leg-length discrepancy at one year of age, progressing to three inches at eight years (Fig. 10-A). In addition to excision of the lateral band, she had a procedure to stimulate growth of the epiphyses about the knee on the ipsilateral side (a procedure which was not considered successful), growth arrest of the epiphyses about the knee on the contralateral side, and tarsal arthrodesis. She has maintained an excellent gait and has had no instability at the ankle. At the most recent examination, when fourteen years old, her leg-length discrepancy was only five-eighths of an inch (Fig. 10-B). This patient did not have an amputation and in all probability will not require one. However, this is not the rule; braces were required in most of these patients after soft-tissue release. Late treatment included stabilization, ankle fusion, leg-lengthening procedures, and growth arrest.

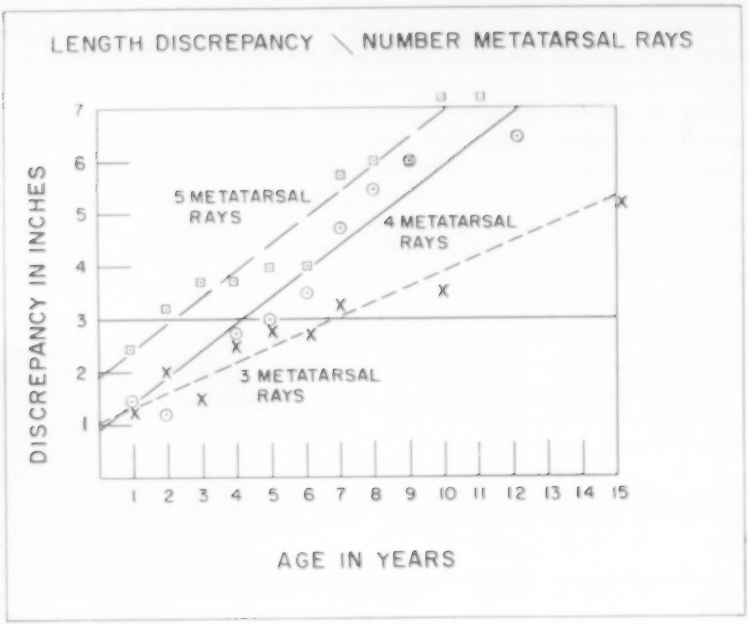

CHART I

Leg-lengthening procedures were carried out on three patients. However, in no instance was complete equalization obtained, and one patient finally had an amputation because of the persistent length discrepancy and foot deformity. The other two, at the time of the last examination, had discrepancies of one and one-half and two inches, respectively.

The procedure of growth arrest in the sound leg must be used with great discretion, since we feel that any effort to control more than three inches of discrepancy by this method is undesirable. Ideally, this procedure should be carried out in an individual with a good foot on the affected side. However, as we have shown, children with a five-rayed foot are usually those with the more pronounced leg-length discrepancies which, we feel, are not amenable to control by this method.

We might summarize then by noting that, in the past, treatment of this deformity has been associated with many hospitalizations, multiple anesthesiae, multiple surgical procedures, and end results which have left a great deal to be desired.

PRESENT APPROACH TO THE PROBLEM

Shortly after 1950, we concluded that most of these limbs eventuate in amputation and began to think in terms of doing this at an earlier age. In support of our thesis, we are presenting four indications for early amputation and use of a prosthesis.

Leg-Length Discrepancy

Long-term follow-up has shown that leg-length discrepancy is present in all of these patients and that it is progressive. At the Shriners' Hospital, growth charts are kept on all of these children. Reviewing the twenty-eight patients in Type II, we found that twenty of these were first seen at age five or younger.

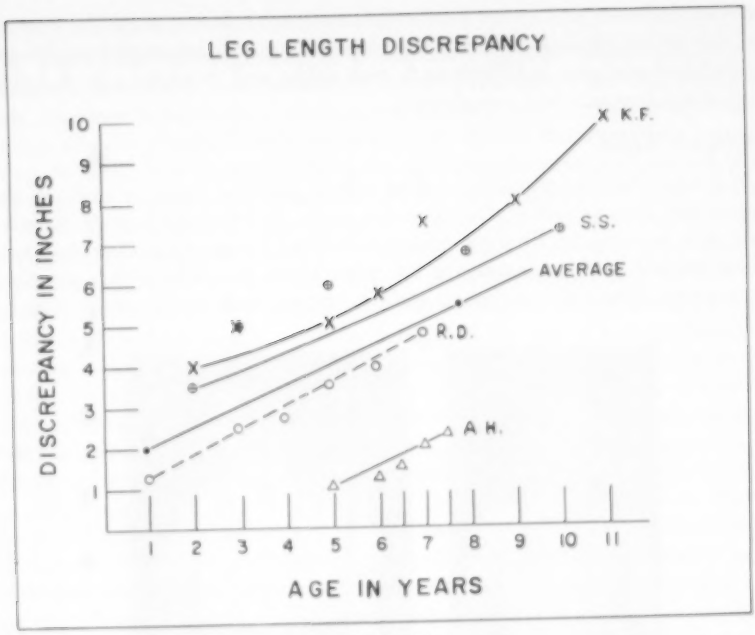

CHART II

Plotting average discrepancies for these youngsters against age, Chart II reveals that the average discrepancy at age one was two inches, whereas the average discrepancy at age eight had increased to five and one-half inches. Individual cases showed ranges which varied considerably. At the one extreme was a boy (K.F.) with a four-inch discrepancy at age two, increasing to a ten-inch discrepancy at age eleven, prior to amputation (Fig. 5-A). At the other extreme was a boy (A.H.) with a one-inch discrepancy at age five, progressing to two and one-quarter inches at age seven and a half. It should be pointed out, however, that he had severe associated deformity of the contralateral foot, which we feel explains the more gradual increase in discrepancy. We observed that in no patient in our series has the discrepancy failed to increase. In those patients in whom leg-length equalization had been attempted by epiphyseal arrest (on the normal side) or leg-lengthening (on the shortened side), complete equalization had never been attained. If one is to strive for complete equalization of leg length, an extremely early epiphyseal arrest or leg-shortening procedure will be necessary. This would involve shortening the child's over-all height, which we will agree is not too great a price to pay for the individual to maintain his own normal foot. However, our study has shown that in those children with an essentially normal foot and five metatarsal rays, the growth discrepancy usually is greatest, appears earliest, and seems to increase most rapidly. For some reason it is associated with shortening of the femur on the ipsilateral side. Conversely, in those individuals with the slowest increase in discrepancy, the foot is usually severely deformed, with marked tarsal abnormality and only three metatarsal rays.

Foot Deformity

In particular, in the children with only three metatarsal rays and severe tarsal abnormalities, foot deformity becomes a major problem. The valgus and equinus deformities are so extreme (Fig. 1) that the individual may almost be walking on

his medial malleolus, and a very poor weight-bearing surface is available. Furthermore, shoe fitting becomes a very real problem. Thus, the deformed irregular foot is a poor functional unit, is difficult to fit with a shoe, and, in addition, is unsightly. Pain is also a frequent late complication.

Psychological Aspect

It is true that, functionally, a child with a platform brace or built-up shoe can carry out most activities that he wishes to do. However, he is quite definitely looked upon as a cripple. He is never certain of being accepted by other children or of being wanted in their games. On the other hand, the child with a prosthesis looks normal (Fig. 2-B). Although children report that in the early stages of

FIG. 2-A

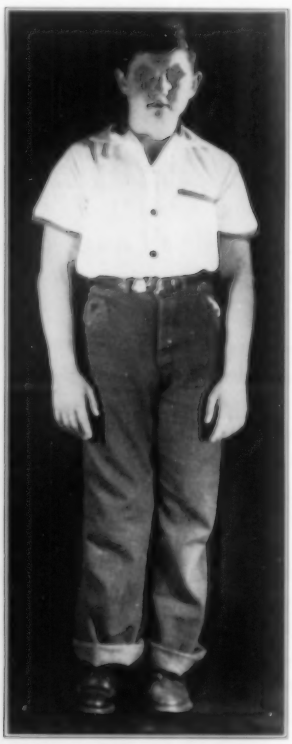

FIG. 2-B

Fig. 2-A: F.G. With this platform brace this child was able to take part in any activity, but the brace labeled him as a cripple.

Fig. 2-B: After end-bearing amputation and a Syme prosthesis, appearance and function are both improved, and the boy is considered to be normal by his playmates.

prosthetic wear, their playmates want to look at their leg and are curious about it, these same playmates very quickly accept the prosthesis as a part of the individual. The patient functions on a higher level, and we have observed rather dramatic changes in personality. The appearance of a child after amputation and fitting with a prosthesis cannot be compared with that prior to this treatment (Fig. 7-C). We take great pride in our clinic in demonstrating the excellent gait of most patients. Frequently, visitors, residents, or staff men are unable to recognize the prosthetic gait.

Economic Considerations

Those patients treated by early conservative regimen (plaster cast, soft-tissue release, and eventual bone procedures) required multiple or prolonged hospitalization. Leg-length discrepancy continued to increase, and in many, eventual amputation was the solution. Early amputation eliminates these multiple hospitalizations. It is true that prosthetic limbs are expensive, but not nearly so expensive as prolonged or repeated hospitalization. At the time our amputee clinic was organized, we decided, among other things, to study costs. The problem of prosthetic fitting in a growing child is an ever-present one, but clinic visits for evaluation at three or four-month intervals are certainly no more frequent than those of a child wearing braces or simply being followed as an out-patient. In a rapidly growing child, the prosthesis may have to be changed at the end of a year. However, we have had several of these children wear the same prosthesis for four or five years, during which period lengthening may have been carried out three or four times, and socket adjustments similarly made. With the newer prostheses, using a patellar tendon-bearing socket and SACH foot, there are fewer moving parts, hence less need for repairs, and, we would anticipate, a much longer prosthetic life.

Having decided upon amputation as the form of treatment, one must next make a decision as to the type of amputation to be carried out. In boys, we have attempted to preserve end-bearing. In the earlier cases these children's feet had been stabilized, and in some instances, ankle fusion had been carried out. Consequently, amputation was simply carried out through the mid-part of the foot, or just proximal to this level, preserving the heel pad. Subsequently, a one-stage procedure was performed in which the hind part of the foot was fused to the tibia, either removing the talus altogether and fusing the calcaneus to the tibia, or doing a single-stage tibiotalocalcaneal fusion and amputation through the mid-part of the foot (Fig. 3). An effort is made to preserve the distal tibial epiphysis by careful removal of the articular cartilage of the tibia without trauma to the epiphysis, except in those patients in whom the epiphysis is noted to be deformed and in whom it was thought that this would result in eventual valgus angulation of the stump. In these latter patients, the epiphysis is intentionally destroyed. We feel that every effort should be made to preserve the distal tibial epiphysis since growth does occur; we have observed up to three and one-half inches of growth in the tibial stump with this type of amputation during a five-year follow-up period. In no instance have we felt it necessary to osteotomize the tibia prior to amputation because of bowing. However, one patient (Case 4) did have tibial osteotomies carried out some seven years prior to his amputations. Prosthetically, this type of end-bearing stump is very easy to fit since there is always sufficient length discrepancy to permit room for a SACH foot. With the development of the Canadian-type Syme prosthesis, we are considering end-bearing amputation in girls. Previously, girls were treated by below-the-knee amputation since the prosthesis was considered cosmetically more favorable. The current development, however, presents a cosmetically acceptable limb and, at the same time, preserves end-bearing which is of great utility to the patient in the event of an emergency.

RESULTS

In twenty-eight Type II patients, amputation was recommended in twenty-three and carried out in twenty. Of these twenty patients, twelve were boys; eleven with amputation with an end-bearing stump and one with a standard below-the-knee amputation. There were eight girls, all of whom were treated by below-the-knee amputation. Only four of these amputations were performed prior to 1950.

TABLE II

RESULTS IN EIGHT PATIENTS WITHOUT AMPUTATION

Patient	No. of Metatarsal Rays	Surgical Procedures	Final Result
P.A.	3	Mid-tarsal wedge osteotomy; leg-lengthening, 3¼ inches	1¾ inches discrepancy at age 15
M.D.	4	Phemister, tibia and femur; leg-lengthening, 3 inches	2 inches discrepancy at age 17
G.F.	4	(Lost to follow-up)	4½ inches discrepancy at age 13; refused amputation
R.D.	3	Transferred to another clinic	4 inches discrepancy at age 6; refused amputation
A.H.*	4	None	2¼ inches discrepancy at age 7½
P.D.*	4	None	4¾ inches discrepancy at age 7; refuses amputation
D.N.*	5	Phemister, tibia and femur	3 inches discrepancy at age 11
J.R.*	5	Excision of lateral band; growth stimulation; stapling; osteotomy for valgus deformity	⅝ of an inch discrepancy at age 14

* Patient still under treatment.

TABLE III

TWENTY PATIENTS WITH AMPUTATION

Patient	Sex	Leg-Length Discrepancy at Amputation (*Inches*)	Age at Amputation (*Years*)	No. of Metatarsal Rays	Type of Amputation
P.B.	F	3½	5	4	Below-the-knee
T.B.	M	5½	9	5	End-bearing
K.F.	M	10	11	5	End-bearing
P.G.	F	3½	2½	5	Below-the-knee
F.G.	M	2	16	5	End-bearing
A.G.	M	5½	15	3	End-bearing
K.H.	M	3¼	3½	4	End-bearing
L.L.	M	3	4	3	End-bearing
M.M.	F	2¼	5	3	Below-the-knee
C.M.	M	2	6	3	End-bearing
M.P.	F	4½	6	3	Below-the-knee
F.P.	F	4¾	8	3	Below-the-knee
J.S.	M	3	7	3	Below-the-knee
S.S.	F	7¼	10	5	Below-the-knee
S.S.	F	6½	13	4	Below-the-knee
S.T.	M	2¼	5	3	End-bearing
R.T.	M	4¾	13	4	End-bearing
J.W.	M	3¼	6	3	End-bearing
J.E.	M	3	22 mos.	5	End-bearing
P.G.	F	4	7	3	Below-the-knee

Leg-length discrepancy at the time of amputation in the twenty patients ranged from two to ten inches, with an average of 4.16 inches. The youngest patient underwent amputation at twenty-two months of age and was fitted with his prosthesis at the age of twenty-four months. At the time of amputation he had a leg-length discrepancy of three inches. The oldest child in this series underwent amputation at sixteen years of age, after a leg-lengthening procedure had failed to produce sufficient length. The average age of the twenty patients undergoing

amputation was seven and a half years. All patients who had amputation are considered to have had excellent results.

The eight Type II patients who did not have amputation must be considered individually. In these eight patients, two had leg-lengthening procedures and have since left our care: the first with leg-lengthening of three and one-quarter inches had a residual discrepancy of one and three-quarter inches at age fifteen; the sec-

FIG. 3

An excellent end-bearing stump is left after tibiotalocalcaneal fusion and amputation of the fore part of the foot.

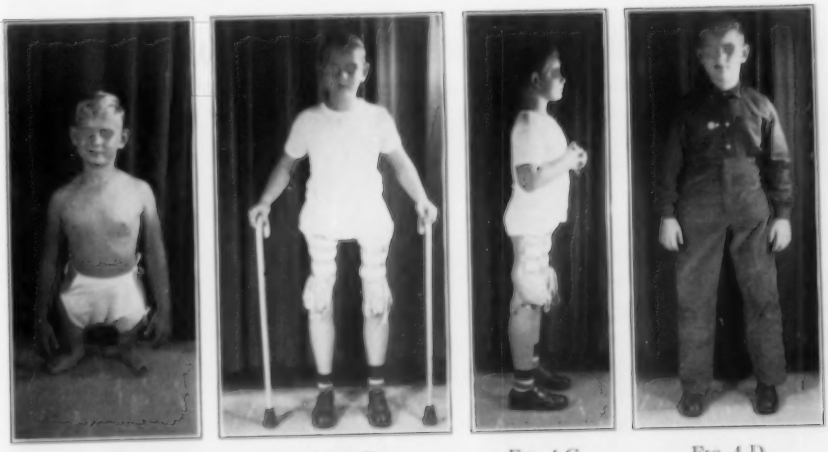

FIG. 4-A FIG. 4-B FIG. 4-C FIG. 4-D

Fig. 4-A: R.M. Bilateral congenital absence of the fibula with aplastic femora.
Fig. 4-B: The boy was fitted with articulated limbs, without amputation; walking was started with the aid of canes.
Figs. 4-C and 4-D: Within six weeks the boy discarded his canes and has realized his ambition to be as tall as other children his age.

ond, who had a Phemister procedure on the sound limb at age eleven and lengthening of three inches at fourteen, had a residual discrepancy of two inches at age seventeen. A third child left our care at age thirteen with four and one-half inches of discrepancy after refusing amputation, and a fourth child left our care at age six, with a four-inch discrepancy after refusing amputation. Four children still remain under our care: a seven-year-old girl with a discrepancy of four and three-quarter inches who has refused amputation; an eleven-year-old boy (Case 5) with a three-inch discrepancy despite Phemister procedures on both femur and tibia to arrest growth of the normal leg, who is being considered for amputation as soon as permission is obtained from his family; and another boy, seven and one-half years old, who has two and one-quarter inches of shortening with a reasonably good foot

and who may do well with a leg-length equalization procedure. The last case is our single triumph in conservative management of congenital absence of the fibula: this fourteen-year-old girl, after multiple surgical procedures, had a good foot and only five-eighths of an inch discrepancy (Fig. 10-B).

In the Type III group, only six amputations were carried out on five patients. Two additional patients with bilateral absent fibulae were treated with prosthetic fitting without amputation (Figs. 4-A, 4-B, and 4-C). Each of these, in addition to absent fibulae, had bilateral hypoplastic femora, resulting in a shortened stature which was the major complaint. These children were fitted with Syme-type sockets, with an opening at the bottom of the socket for the foot and articulated knee and ankle joints. This, in effect, was a stilt-type of mechanism which the patients learned to handle quite well; in both children excellent acceptance of the prosthesis has been demonstrated over the period of follow-up. The first patient, a girl, was fitted in 1954, at the age of thirteen. She has since been discharged from the clinic, is now married, and has a normal baby of her own. She is very happy and still wears her artificial limbs all day. The second patient, a boy, was fitted at the age of nine and has been followed for two years; his acceptance of the prostheses is excellent, and he uses them well, without crutches or canes (Figs. 4-C and 4-D). The remaining patients in Type III without a length-discrepancy problem have managed to do reasonably well despite their foot deformities.

ACCEPTANCE OF PROSTHESIS

In no case has there been any question of acceptance of a prosthesis. The youngest patient was fitted at the age of twenty-four months. It was difficult for him to hold his prosthesis on, but eventually this was accomplished with shoulder-strap suspension.

GAIT

End-bearing amputations give the most stable type of gait. As a matter of fact, the children with these amputations are able to walk on their unprotected stumps, despite rather pronounced length discrepancies. All of these children have excellent gaits. They are able to ride a bicycle, play baseball and football, and ice skate; one boy even skis. All the children with below-the-knee amputations have developed a uniformly good gait pattern. More recently, using the patellar tendon-bearing below-the-knee prosthesis, we are having even better results.

One point should be made at this time. As shown earlier, many of these children have a femoral deformity which may involve the hip joint itself, causing a hip limp. Despite any amputation performed or prosthesis fitted, this hip limp will not be eliminated. In the unusual case, the child with an extremely hypoplastic femur and dysplastic hip, it may be eventually necessary to convert the Syme prosthesis to an above-the-knee prosthesis with ischial weight-bearing to provide the patient with needed hip stability.

COMPLICATIONS

The only significant complication which we have experienced so far in these amputations is overgrowth of the tibia with the formation of a bone spike in four below-the-knee amputations; these required revision of the stump. These four patients have been followed from one to four and one-half years since revision and have had no further trouble. We have also noted the development of callosities at the distal tip of the end-bearing stumps. These callosities, as a rule, are not painful and have not required surgical revision. In one patient pain developed in the stumps after tibial osteotomies to correct valgus deformity of the knees (Case

4). We have had no instances of neuroma or symptomatic phantom limb. The major difficulty has been breakdown of the prostheses caused by hard usage by these children. Wood with rawhide covering is very susceptible to water, and

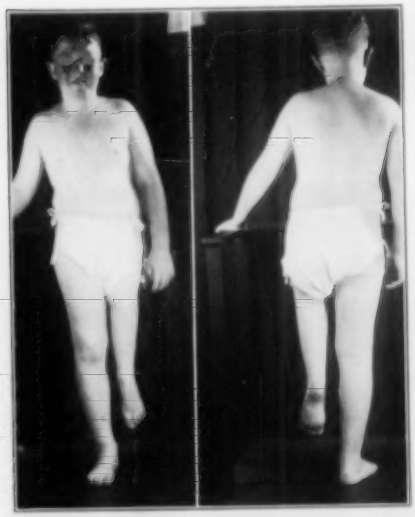

FIG. 5-A

FIG. 5-B

FIG. 5-C

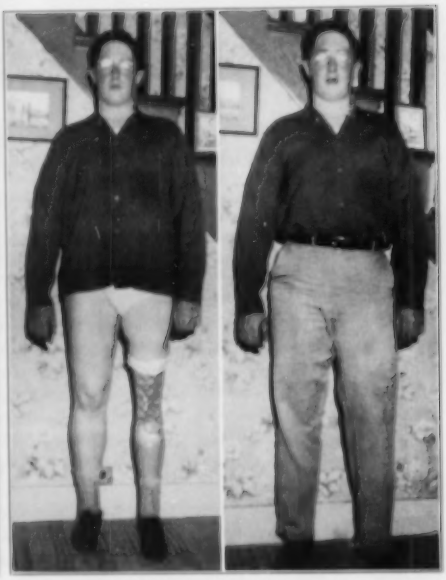

FIG. 5-D

Fig. 5-A: Case 1. K.F. In this boy with a shortened femoral segment, the leg-length discrepancy increased to ten inches prior to amputation at the age of eleven years. Note the difference in knee levels.

Fig. 5-B: Roentgenogram showing both the length discrepancy of the femur and the absent fibula.

Fig. 5-C: Wearing this brace prior to amputation, this boy was quite active, but still somewhat limited.

Fig. 5-D: Following amputation, his sphere of activity increased so considerably that he was able to take part in pole vaulting, skiing, and, in fact, any other sports he desired. At the age of eighteen, he had an excellent functional and cosmetic result.

children seem to walk in more than their share of water. It is very likely that with the increased use of plastic-laminated sockets we shall have less difficulty of this type.

CASE REPORTS

Case 1. K.F. (Figs. 5-A, 5-B, 5-C, and 5-D) was born on December 19, 1943. He was first seen on October 13, 1945, with congenital absence of the left fibula, hypoplasia of the left femur, a length discrepancy of four inches, anterior bowing of the left tibia, and an equinovalgus deformity of the left foot, which had five normal rays. There was some question as to the integrity of the hip at this time. Roentgenograms revealed the presence of ipsilateral coxa vara; the femur was quite short

Fig. 6-A Fig. 6-B Fig. 6-C Fig. 6-D

Fig. 6-A: Case 2. S.T. A photograph made before amputation shows the typical appearance of unilateral congenital absence of the fibula with bowing of the tibia, dimpling of the skin, deformity of the foot, and leg-length discrepancy.

Fig. 6-B: After amputation, this boy has an excellent stump, with no sensitivity or tenderness, on which he can bear weight and walk in case of emergency.

Fig. 6-C: With his prosthesis on, this boy stands erect and walks with an excellent gait.

Fig. 6-D: Wearing clothes, there is little to indicate that this boy has had an amputation. The patient and his family are pleased with both the cosmetic and the functional result.

compared with the contralateral side. The tarsal bones of the left foot were said to be normal. The left fibula was completely absent. This boy was fitted with a platform brace. He functioned reasonably well with one new brace from September 1952 until June 1954. At that time his leg-length discrepancy had increased to ten inches and a subtrochanteric osteotomy was carried out to correct the hip deformity. Two months later subtalar arthrodesis and ankle fusion were performed, followed by amputation of the fore part of the foot in October 1954. The child was subsequently fitted with a Syme's type of prosthesis, with which he developed excellent function, despite the hip difficulty and the marked discrepancy in knee level. In 1956, this boy reported that he was riding his bicycle, pole-vaulting, and skiing. A new limb was obtained in June 1959, after the original limb had been used for four and one-half years, during which time the prosthesis was lengthened on three occasions, with other repairs necessary, including change of the foot. At the time of discharge from the clinic this boy was functioning at an excellent level and was extremely happy with his prosthesis.

Case 2. S.T. (Figs. 6-A, 6-B, 6-C, and 6-D) was born on October 21, 1953. He was first seen in April 1954, with congenital absence of the right fibula, absence of the fourth and fifth rays combined with equinovalgus deformity of the right foot, hypoplasia of the right femur, a length discrepancy of one and three-quarter inches, and anterior bowing of the tibia with dimpling over the apex of the bow. He was fitted with a brace with a lift and did reasonably well. It was of interest that this boy was one of twins, the other having no deformity, whose general appearance suggested that they might be identical; however, obstetrical history was unobtainable. When the twins were three years old, there was a difference of one inch in their over-all height. Under observation, the

patient showed gradual increase in his leg-length discrepancy; by July 1959, the discrepancy was two and one-half inches. It was felt that this boy might do well if his length discrepancy did not increase, but there were indications that the discrepancy was increasing. Because this situation was coupled with a deformity of the foot (a three-rayed foot) and with roentgenographic evidence of deformity of the distal tibial epiphysis of this leg, it was felt that amputation and prosthetic restoration were indicated. End-bearing amputation was carried out on August 6, 1959. The boy was fitted with a Syme's type of prosthesis with SACH foot; he has since been fully active without complaint. The parents and the patient are quite pleased with both the cosmetic and the functional result.

Case 3. P.B. (Figs. 7-A, 7-B, and 7-C) was born on October 21, 1950, and was first seen in June 1952, when she was found to have congenital absence of the right fibula, congenital dysplasia

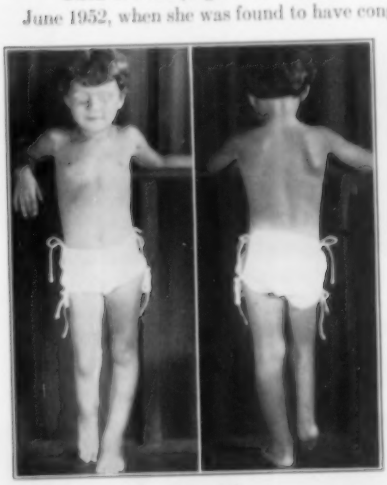

Fig. 7-A

Fig. 7-B

Fig. 7-C

Fig. 7-A: Case 3. P.B. Congenital absence of the fibula in a girl four years and ten months of age. There is a leg-length discrepancy of three and one-half inches.

Fig. 7-B: After amputation, the child was fitted with a standard below-the-knee prosthesis; she walked with an excellent gait and rapidly attained full functional capacity.

Fig. 7-C: Five years after amputation, wearing the patellar tendon-bearing prosthesis, the child has no limitations. She skips, jumps rope, dances, and is even able to walk on stilts.

of the right hip, and leg-length discrepancy of one and one-quarter inches. She was admitted to the Shriners' Hospital in June 1952, at which time she was noted to have an absence of the fifth metatarsal ray, anteromedial bowing of the tibia, and equinovalgus deformity of the foot. She was treated by plaster-cast correction of the foot deformity until July, at which time posterior capsulotomy and lengthening of the Achilles tendon were carried out. She was subsequently fitted with a platform brace for maintenance of leg length and wore this until the time of her second admission in August 1955. At this time her right hip was normal; her right leg showed persistent anteromedial bowing. The valgus deformity of the right foot persisted, along with a leg-length discrepancy of three and one-half inches. O. August 19, 1955, below-the-knee amputation was carried out, and a prosthesis was fitted in November 1955. The child developed an excellent prosthetic gait rather promptly and carried on in normal fashion until September 1958, when some overgrowth of the tibia was noted. This was not considered to be of consequence, but in May 1959 a small bursa had developed over the tip of the tibial stump. In June 1959, after revision of the stump was carried out and the prosthesis was adjusted, the child quickly resumed normal activity. Her most recent prosthesis, fitted in August 1960, is a patellar tendon-bearing plastic-laminated socket with SACH foot. She is fully active; she ice skates, roller skates, runs, jumps, skips rope, and is even able to walk on stilts. Both mother and child are extremely happy and much prefer the prosthetic restoration to the brace she wore prior to amputation.

Case 4. M.S. (Figs. 8-A through 8-E) was born on March 22, 1947. When he was first examined on October 16, 1948, he was found to have bilateral congenital absence of the fibula, anterior bowing of both tibiae with dimples over the apex of the bow, severe equinovalgus deformities, and absent fourth and fifth metatarsal rays on the right; third, fourth, and fifth on the left. In May 1949, he was admitted to the hospital where soft-tissue release, including tendon-lengthening and

FIG. 8-A

FIG. 8-B

Fig. 8-A: Case 4. M.S. Bilateral congenital absence of the fibula, with severe foot deformities, knee-flexion deformity, and marked bowing of the tibiae. The patient was treated conservatively, but the deformities recurred.

Fig. 8-B: Photographs made before amputation showed the severe foot deformities, as well as hip-flexion deformities and knee flexion with moderate valgus deformity.

FIG. 8-C

FIG. 8-D

FIG. 8-E

Fig. 8-C: End-bearing amputation has been carried out and the boy has been fitted with bilateral Syme prostheses. Note the prosthesis is built to accommodate the valgus deformity of the knee.

Fig. 8-D: Without his prostheses, the boy is able to walk on his stumps without pain or complaint. With his prostheses he is for the first time as tall as other children his age since his prostheses have added approximately eight inches to his height.

Fig. 8-E: After osteotomy of his legs, the boy was fitted with new limbs. Note the velcro closures replacing the standard lacers on the Syme prostheses.

capsulotomy, was carried out, and osteotomy of both tibiae was done in an effort to correct the bowing. He remained in the hospital for four months and was discharged walking, but with persisting deformities of both feet. The foot deformities increased and flexion deformities of the knees and hips developed. As early as 1950, bilateral amputation and prostheses were discussed but these procedures were not carried out until April 1956, when, after stretching of the knee-flexion deformities, bilateral amputation of the fore part of the foot with tibiocalcaneal fusion was done. A

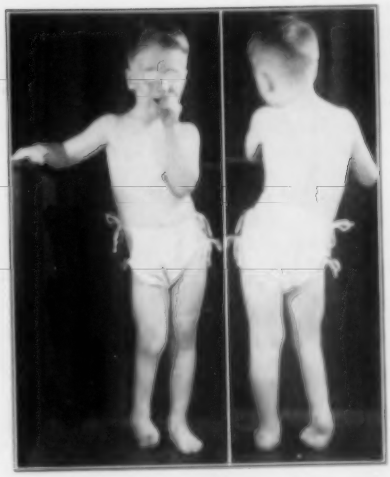

FIG. 9-A

FIG. 9-B

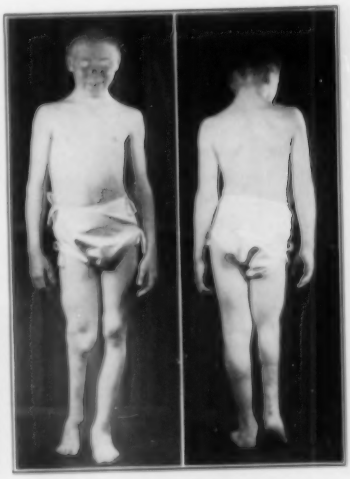

FIG. 9-C

Fig. 9-A: Case 5. D.N. This boy with congenital absence of the fibula was one of two in this series with varus deformity of the foot present at birth and recurrent after correction by serial wedging plaster casts.

Fig. 9-B: Discrepancy gradually increased to four inches by the time the boy was eight and a half years old.

Fig. 9-C: In June 1960, this boy still has a three-inch length discrepancy, and will probably require amputation.

moderate valgus deformity of the knees was accepted. On November 2, 1956, the boy was fitted with the bilateral Syme's type of prostheses. He walked rather readily and, at the time of discharge, November 24, 1956, was fully ambulatory, either on his stumps or on his prostheses. After these procedures he changed from a markedly introverted child to a definite extrovert. His school work improved considerably. He became active, riding a bicycle and carrying on with other activities. He did well until December 1959, when he required a new pair of prostheses. At this time, prior to constructing new prostheses, a decision was made to attempt to correct the rather pronounced valgus deformity, which persisted in both legs. Bilateral high tibial osteotomy was carried out. After union was achieved it was noted that there was some residual deformity on the right side, but the boy's new prostheses were fitted in spite of it. The boy had a little difficulty in adjusting to them because of a rotational problem, but eventually he was discharged home, walking with a good gait. During the next ten months, however, difficulty gradually developed, particularly pain in the right stump, which was felt to be due to malalignment of the prosthesis and shift in weight-bearing areas after osteotomy. In an effort to correct this difficulty, the boy was readmitted to the hospital in November 1960, for repeat osteotomy. However, after realignment of the prosthesis on the below-the-knee adjustable leg, the difficulty seemed to be corrected, and he was again discharged home improved. This boy is the only child in our series who had significant stump pain, and there is little question in our minds that the pain resulted from the change in alignment of weight-bearing after osteotomy. No revision of his stump is contemplated.

CASE 5. D.N. (Figs. 9-A, 9-B, and 9-C) was born on October 1, 1947, and was first seen on June 26, 1948. He was found to have congenital absence of the right fibula, equinovarus deformity of the right foot, hypoplasia of the ipsilateral femur, abnormal ossification of the distal tibial epiphysis, and a leg-length discrepancy of two and one-half inches. The patient was admitted to Shriners' Hospital in March 1947, and the foot deformity was corrected by serial wedging plaster casts. The patient was then fitted with an extension brace for day wear and a Denis Browne splint for night. After discharge, he was followed as an out-patient, and gradual recurrence of the foot deformity was observed. The boy was readmitted to the hospital in 1952, and at this second admission a length discrepancy of two and three-quarter inches was recorded. Again the deformity was treated with wedging plaster casts, as well as lengthening of the Achilles tendon and posterior release. After correction he was again fitted with a short platform brace and discharged home. The leg-length discrepancy remained approximately the same for three years, from 1952 to 1955. In June 1956, however, when he was re-examined, the discrepancy had increased to four inches. Amputation was considered, but it was decided that because of the gradual progression of the dis-

crepancy it might be possible to control the problem of leg length by growth arrest in the normal limb. Accordingly, in 1958, a Phemister epiphysiodesis of the left femur and tibia was carried out. At this time the brace was replaced by a shoe with a cork lift. At the most recent examination, in June 1960, the leg-length discrepancy was three inches. We are now faced with a situation in which, in all probability, this boy will have to have an amputation performed because of persistent marked discrepancy in leg length. In retrospect, he would probably have been better off with an amputation rather than the attempted equalization of leg length. At the present time he still has his own foot and is wearing the cork-lift shoe, which is cosmetically undesirable.

Case 6. J.R. (Figs. 10-A and 10-B) was born on November 26, 1946, and was first seen on September 27, 1947, when she was found to have congenital absence of the right fibula, a leg-length discrepancy of one inch, valgus deformity of the right foot, and very slight anterior bowing

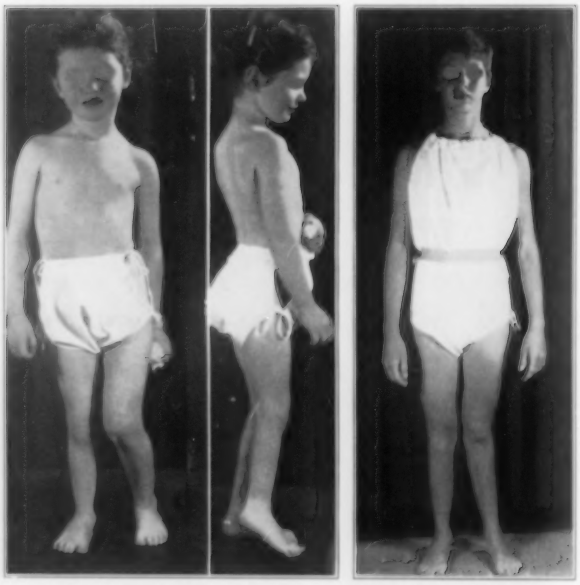

Fig. 10-A Fig. 10-B

Fig. 10-A: Case 6. J.R., with congenital absence of the fibula, is seen at the age of five years with two inches of discrepancy and only moderate foot deformity.

Fig. 10-B: After conservative treatment, the child is shown at the age of fourteen with only five-eighths of an inch discrepancy in leg length; she represents our only successful case of conservative treatment.

of the tibia. The foot was five-rayed and showed, by roentgenogram, when compared with th contralateral side, some alteration in the shape of the talus, with diminished ossification of the tar sal bones throughout. A brace was fitted, and the child was followed as an out-patient. Her growth discrepancy progressed very slowly, but there was persistent valgus deformity of the foot. She was admitted to the hospital in December 1951, at which time the leg-length discrepancy was two inches. An effort was made to stimulate growth in the epiphyses of the knee and to correct the deformity of the foot by excision of the lateral fibular band. Subsequently, the child was fitted with a platform brace and was again followed as an out-patient. The discrepancy continued to increase, reaching three inches in 1954. During 1955 there was very little change, the discrepancy remaining at three inches. The patient was, therefore, readmitted in December 1955, and stapling of the tibial and femoral epiphyses about the left knee was carried out. She was readmitted in 1957 for replacement of the upper tibial staples, which had backed out. She continued to do well after this procedure, showing progressive diminution in the discrepancy. She was again admitted in August 1960, at which time the discrepancy was five-eighths of an inch, but a valgus deformity of the knee had developed on the stapled side. The staples were removed, the deformity was corrected by osteotomy, and the patient is again walking. This young lady is our only case with reasonable correction of leg-length discrepancy in unilateral absence of the fibula; unquestionably, she will not have to have an amputation.

CASE 7. J.G.W. was born on April 27, 1949, and first seen on April 8, 1950, with a diagnosis of congenital absence of the right fibula. When first examined he had a leg-length discrepancy of one and one-half inches, severe equinovalgus deformity of the foot, anteromedial bowing of the tibia, and absent fourth and fifth metatarsal rays. The boy was admitted to the Shriners' Hospital in April 1951, when correction of the foot deformity was attempted and the tight soft tissues were released. The deformity recurred and the leg-length discrepancy gradually increased while the boy was maintained in a brace with a platform. In October 1954, his discrepancy had increased to three and one-quarter inches; he was then readmitted to the Shriners' Hospital and an end-bearing amputation was carried out. He was fitted with a Syme prosthesis on March 18, 1955. He rapidly attained a good gait and wore the same prosthesis until April 1960, when a new Canadian-type Syme plastic-laminated prosthesis was fitted. This boy continues to be fully active and takes part in all sports. Both the boy and his parents are extremely pleased with the prosthetic restoration.

FIG. 11-A

FIG. 11-B

FIG. 11-C

Fig. 11-A: Case 8. J.E., with congenital absence of the fibula, is seen at the age of twenty-two months with a five-inch leg-length discrepancy and typical clinical findings.

Fig. 11-B: After end-bearing amputation, the boy was fitted with a plastic-laminated socket, but required additional shoulder-harness suspension to hold his limb on.

Fig. 11-C: Clothed, the boy has the appearance of a normal youngster, and his gait is considered satisfactory for a child twenty-four months old.

CASE 8. J.E. (Figs. 11-A, 11-B, and 11-C) was born on September 8, 1958, and was first seen on May 16, 1959, when he was eight months old. At that time he was found to have congenital absence of the left fibula, presumed dysplasia of the left hip, three inches of shortening of the left leg, and anterior bowing of the left tibia, with a dimple over the apex of the angulation. There was also equinovalgus deformity of the left foot, which had five metatarsal rays.

Roentgenograms revealed varus deformity of the left femoral neck with hypoplasia of the left femur, but no dysplasia of the hip joint. Absence of the fibula was verified by roentgenogram. There was shortening of both the femur and the tibia.

The child was admitted to the hospital on July 4, 1960, by which time his length discrepancy had increased to five inches when measured from the anterior superior spine of the ilium to the plantar surface of the heel.

On July 22, 1960, when the patient was twenty-two months old, a Syme amputation was carried out; two months later, on September 23, 1960, the child was fitted with a prosthesis, using a below-the-knee adjustable leg until the final prosthesis was delivered. This child was slow to walk because of difficulty in holding the prosthesis on. Finally, he was fitted with a suspender-type shoulder harness; shortly thereafter he began to walk and has carried on well since. The parents are quite satisfied with the result to date.

SUMMARY

Sixty-two instances of congenital absence of the fibula occurring in forty-eight patients are reported. The transition of treatment from the conservative

approach of correction of deformity, using plaster casts, bracing, platform braces, and built-up shoes, to the more radical approach of amputation and prosthesis is presented. End-bearing stumps are recommended for both boys and girls because of the utility of the stump, with or without the prosthesis; the more stable prosthetic gait with end-bearing; and the minimum prosthetic upkeep of these prostheses with few moving parts. Absence of complications in the stump is an important feature in these end-bearing amputations, with no revisions reported to date. The procedure of earlier amputation and fitting of a prosthesis is recommended.

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DISCUSSION

Dr. Charles H. Frantz, Grand Rapids, Michigan: Dr. Kruger and Dr. Talbott have presented an interesting analysis of their approach to so-called congenital absence of the fibula. This entity has been recognized for many years, having been first described in the late seventeenth century. During the twentieth century, amputation has been an accepted practice in treating this condition. Since 1940, Dr. Carl Badgley has been advocating disarticulation at the ankle.

Congenital absence of the fibula is more than a simple absence. I prefer to call it paraxial fibular hemimelia. I should like to stress the significance of the distal tibial epiphyseal plate, which is deficient in this condition.

Dr. Kruger and Dr. Talbott report forty-eight cases, 29 per cent of which were bilateral. Our series of thirty-four cases parallels this, with an incidence of 24 per cent of bilateral involvement. The majority of children with this deficiency have unilateral involvement. Present indications are that from a genetic standpoint, this has a sporadic incidence and is passively recessive; it sometimes accompanies other limb abnormalities.

I fully agree with the authors' emphasis on the importance of leg-length discrepancy, the psychological implications of the word *cripple*, and the unhappy past experience with multiple hospitalizations and prolonged morbidity from numerous attempts at foot correction. They report twenty-four amputations in forty-eight patients, an incidence of 50 per cent. It is interesting to note that only 10 per cent of their patients underwent amputation prior to 1950 and 42 per cent since 1950. This seems to indicate increasing appreciation of the efficiency with which modern prostheses can be utilized by the young child. This trend is further manifested by the fact that Dr. Kruger and Dr. Talbott performed amputation on a child as young as twenty-two months of age. Our youngest patient was nineteen months of age at amputation.

The authors point out that 10 per cent of fibular absences are accompanied by other anomalies. One of the most common severe anomalies of the limbs is a short femur; in twelve of our cases of femoral deficiency, fibular hemimelia accompanied this major anomaly.

From the surgical standpoint in the series here presented, complications included tibial overgrowth requiring revision of the stump in four instances. This is a phenomenon peculiar to growing children and can be expected in any child under the age of nine undergoing long-bone amputation. Overgrowth after amputation is seen in the fibula, tibia, and humerus in decreasing frequency. We have in the past performed below-the-knee amputations on children close to maturity. Our present practice is ankle disarticulation, particularly in the young child, to preserve what growth potential may be present in a deficient distal tibial epiphysis. This procedure allows end-bearing. In time, the heel pad may migrate posteriorly and proximally, but this alteration in position has not impaired comfortable end-bearing in our experience. We have not resorted to osteotomy for valgus deformity of the tibia after amputation or disarticulation. Proper socket alignment will care for this.

I would be disinclined to undertake any surgical procedure that might injure the distal epiphyseal plate in children.

(Continued on page 699)

The Bioelectric Factors in Amphibian-Limb Regeneration*

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The replacement of lost body parts by a specific growth process known as regeneration is an ability shared, to a varying extent, by all living things. In general, as one follows the evolutionary sequence, the ability becomes increasingly restricted. In man, the process is limited to the regeneration of certain tissues only, notably skin and bone. In a child the diaphysis of a long bone can be regenerated provided the periosteal tube is intact, whereas in an adult a fracture of a long bone can heal by replacement of the missing portion with functional osseous tissue. Although there is little doubt that factors such as nutrition, vascularity, and immobilization all play important roles in supporting this osseous healing process, the basic processes of cellular de-differentiation and subsequent re-differentiation which produce a replica of the missing portion represent true tissue regeneration. This process of bone healing is in marked contrast to the healing mechanisms in most other human tissues in which fibrous connective tissue is used to bridge the gap. It is evident, therefore, that the process of regenerative healing must entail specific factors not operating in other less adequate types of tissue healing. To control this type of tissue healing adequately, these specific factors must be identified and themselves controlled.

It is reasonable to expect that the same general controlling mechanisms are operative for all types of regeneration, and that knowledge of the regenerative process in another vertebrate may furnish a basis for a study of human regeneration. Fortunately, the peak of regenerative ability, as judged by the complexity of the structures regenerated, is present within the vertebrate phylum. The urodela, or salamanders, are present-day examples of the basic vertebrate type from which the higher vertebrates have been derived. Their fore and hind limbs are equivalent in anatomical structure and complexity to the human upper and lower extremities. Nevertheless, the larval-stage salamander is capable of regenerating a perfect replica of one of its limbs in a period of thirty to forty days. The adult salamander is similarly capable, although the required time is somewhat longer and the regenerated extremity may be slightly smaller than normal (Fig. 1). This process is so dramatically evident that it has stimulated study for literally centuries†. However, the basic controlling factors in the regenerative process and the factors operating to reduce the process in mammals have successfully resisted investigation until recently. Within the past few years, some significant observations have been made and the problem now can be approached from a new aspect.

In one line of inquiry Singer demonstrated the dependence of the regenerative process upon the presence of a critical amount of nerve tissue within the amputation stump [23]. He showed that this effect is not dependent on the type of nerve

* Read at the Combined Meeting of the Orthopaedic Research Society and The American Academy of Orthopaedic Surgeons, Miami Beach, Florida, January 8, 1961.

† Spallanzini (Prodromo, 1768): "But if the above mentioned animals recover their legs—how comes it to pass, that other land animals are not endowed with the same power? Is it to be hoped that they may acquire them by some useful disposition?"

tissue present. In the salamander, if the normal amount of peripheral nerve tissue is reduced by proximal nerve sectioning, then regeneration will not occur until either the missing nerves grow into the area or until neural tissue of any type, but sufficient in amount, is grafted into the area. Under certain specific circumstances, limb regeneration can occur in limbs devoid of nerves (parabiotic twinning [27]), indicating that under these circumstances the neural contribution may possibly be ancillary rather than primary. Although these experiments have, in general, left little doubt that some neural factor is necessary for the process of limb regeneration, the specific responsible factors associated with the nerve have yet to be identified.

Some recent investigations I reported furnished a possible clue to the identity of this neural factor [2]. The existence of direct-current electricity in living organisms was first observed by Galvani in 1792, and has received attention intermittently since then. This type of electrical activity, designated as the *bioelectric*

FIG. 1

An example of the regenerative ability of the salamander. The animal on the left had the right forelimb amputated one week prior to the photograph. The other specimen had the left forelimb removed at the same level fifteen weeks before. The regenerate is somewhat smaller than the normal limb, but the completeness of restoration is evident. These forelimbs are homologous to the human upper extremity, containing a humerus, radius, ulna, and carpal bones, in addition to the homologous soft structures. The regenerate restores almost completely the anatomical complexity and is a functional organ. It will be noted that the long bones, and, particularly, the spine of the specimen with the week-old amputation, are less distinct and appear somewhat less dense than the same structures of the other animal. This observation has been made repeatedly and is not due to any difference in technique. Its significance is unknown at present.

field or the *direct-current field*, must be carefully distinguished from the more familiar action-potential activity of the nerves and muscles. The bioelectric field is a steady-state potential, measured as direct-current potentials, on the surface of living organisms. The action potentials, on the other hand, consist of the transmission of pulses of membrane depolarization along the nerve or muscle fiber. Although the pulses are detected by electrical means, they do not involve the actual flow of an electrical current longitudinally in the fiber [4]. Since the techniques of measurement of action potentials are simpler, and since the action potentials apparently are a prime means of data transmission, this type of activity has been preferentially studied by most investigators.

Much of the work on the direct-current field potentials was done ten to twenty years ago. The concept arrived at then was that the bioelectric field consisted of a simple electrical dipole with no more structural complexity than a positive polarity of the cephalad portion, compared with the caudad portion of the animal. The source of the potential was assumed to be the total electrical activity of all of the cells of the organism. The usual measurements done at that time were between the nose and the tail (cephalad-caudad) or between two other arbitrary points only. Despite this amorphous concept, many observations were made, indicating some relationship between these potentials and various biological activities such as: fluid transport in plants [9,10], anesthesia in animals [5], and ovulation [19], hypnosis [20], and schizophrenia [21] in man. In particular, there appeared to be correlations with growth processes [6,15,16]. In recent years the relationship between direct currents and growth were investigated by artificially applying the currents to the organism. Acceleration of the rate of regenerative growth in tomato plants [23] and, conversely, complete regression of malignant tumors in mice [12] were reported to follow application of currents of appropriate polarity.

It therefore appeared worthwhile to re-evaluate the entire problem of the bioelectric field and its relationship to growth processes. The salamander was chosen as the experimental animal in view of its regenerative ability and its position in the vertebrate phylum. Furthermore, the moist skin of these animals permitted direct-current measurements to be done with less technical difficulty. Utilizing the techniques of equipotential line plotting (determining the imaginary lines on the surface of the animal which connect all points of equal potential), a complete field plot of the bioelectric field can be made. (For further concepts of the electrical field, the interested reader is referred to references 14 and 18.). If the bioelectric field is a controlling factor in growth processes, such control should be indicated by some change from the normal in the field plot. Therefore, the initial observations were concentrated on a determination of the field configuration in the intact animal. Rather than finding the expected simple dipole, a complex field was found with multiple positive areas, or electron sinks, and multiple negative areas, or electron sources (Fig. 2). This pattern was found uniformly in over fifty individuals of several different species. It became apparent that the spatial configuration of the bioelectric field coincided with the gross anatomical arrangement of the central nervous system. The positive areas (electron sinks) coincided with the three major cellular accumulations of the neuraxis (cranial, brachial, and lumbar enlargements). The negative areas (electron sources) correlated with the terminations of the major peripheral nerve outflows from these same areas. It was therefore postulated that the direct-current potentials were generated within the cellular aggregates and distributed by the peripheral nerves, with a completion of the circuit made through the soft tissues (or in the aquatic forms, through the environment). This hypothesis was tested in a number of ways. It was noted that complete section (adjacent to the cord) of the nerves to one ex-

tremity produced a prompt drop of the potential along the extremity to nearly zero. By applying the Hall effect (a physical measurement involving the interaction between a steady magnetic field and a moving direct current) it was shown that there was actual flow of electrical charges longitudinally in an extremity and that this flow ceased after nerve section. Finally, an analogue device, or model, of the central nervous system was constructed and was found to produce the same field plot and to show the same behavior as the living prototype. It must be emphasized, however, that although these experiments show a distinct relationship between the central nervous system and the bioelectric field, the specific tissue in the central nervous system responsible for the generation and transmission of the currents has not been identified. At this time we cannot say whether the

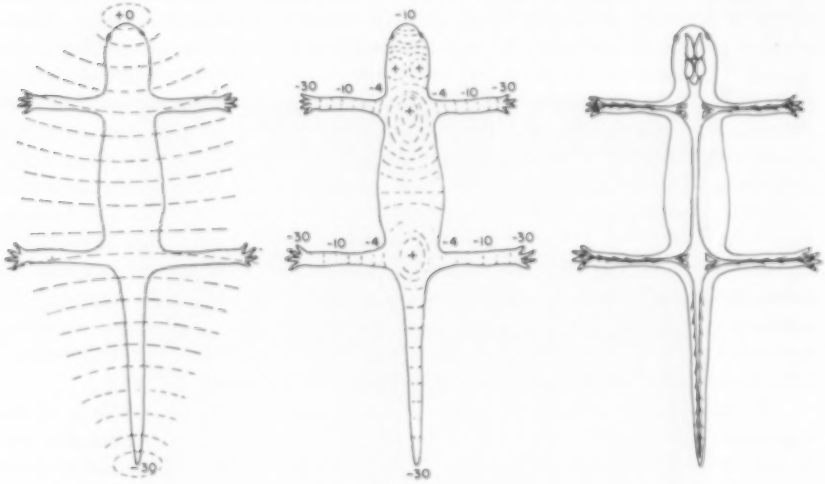

FIG. 2

The bioelectric field, previous dipole concept compared with organized field concept as related to the central nervous system.

The outline drawing on the left indicates the total body potential as measured by previous investigators (tip of nose reference electrode, tip of tail recording electrode, animal immersed in fluid medium). The equipotential lines as drawn represent the theoretical dipole field that was postulated. Such field determinations were never reported in the literature. This is the type of field plot I expected to find when the project was first begun.

The middle outline drawing indicates the field plot that was actually found (using the two electrode equipotential line-plotting technique on an animal kept moist, but not immersed, in solution). The numerical values inserted along the extremities are typical ones found on an animal about to recover from anesthesia when the head sink areas are used as the reference electrode site and the recording electrode is located at the other appropriate sites.

The outline drawing at the right represents the gross arrangements of the central nervous system in the salamander. It will be noted that the neuraxis contains three major cellular accumulations, with major peripheral nerve trunks extending distally from each. The correspondence between the cellular accumulations and the positive sink areas, and between the nerve-trunk terminations and the negative sources, is apparent.

neurons themselves, the neuropil, or the supporting elements—the glia and Schwann cells—are the important structures.

These observations on the bioelectric field indicate that it is a highly organized activity, generated within and transmitted by elements of the central nervous system. It appeared that, as such, it could function as a very primitive data transmission and control system. This concept permits a restudy of many life processes, including growth, which are obviously under precise control but for which control systems have not yet been identified. In this paper I shall be concerned with limb regeneration, perhaps the highest expression of organized growth in the adult

animal. The demonstrated relationship between the central nervous system and the bioelectric field would appear to furnish a logical basis for Singer's observation relating any type of nerve tissue to regeneration. It appeared quite possible that the basic phenomenon that Singer observed was nerve-related direct-current electricity rather than specific neural function. A preliminary study of this relationship between the bioelectric field and growth-control processes has neen completed and some encouraging results obtained.

METHODS

Several species of salamanders with regenerative ability (*T. viridescens*, *A. tigrinum*, *A. opacuum*, and *N. maculosus*) and a non-regenerating, but closely related amphibian, the grass frog (*R. pipiens*), were used as the experimental animals. The techniques of measurement used were the same as previously described [2] and will not be discussed here. The only change in this technique has been a refinement in the recording apparatus, permitting the simultaneous monitoring of the direct-current voltages from as many as eight different areas of the same animal. In the experiments in which direct current was administered to the animals, a precision direct-current voltage divider type of supply was used along with solid, silver-silver chloride electrodes. One electrode was large and encased in a pad soaked in saline solution to serve as the reference electrode. The other was small and glass mounted and was applied directly to the amputation stump. Animals were anesthetized with tricaine for most of the experiments, although the effects of other anesthetic agents on the field potentials were also studied. Deep anesthesia, regardless of the inducing agent, is accompanied by a complete field reversal; that is, the extremities become positive and the cellular areas become negative. Despite this polarity reversal, the equipotential lines remain the same and the field plot remains constant. Interestingly, the degree of reversal of field polarity correlates well with the depth of anesthesia, being fully reversed with the deepest anesthesia and slowly returning to normal as anesthesia diminishes. During the period (five to ten minutes) immediately preceding full recovery from anesthesia, the animals demonstrated a field plot of normal polarity and potential. These factors were taken into consideration in making the measurements. Determinations on wound and regenerate potentials were done just as the animals were fully recovered from anesthesia. In some instances, when restraint was used on non-anesthetized animals, similar results were obtained.

RESULTS

The presentation of experimental results will be divided into four sections: the electrical changes immediately associated with amputation; the subsequent changes during the healing or regenerative phase; the electrical changes during fracture healing; and the results of artificially augmenting the electrical changes in the course of regeneration.

Section One

Limb amputation in both regenerating and non-regenerating forms was followed immediately by a complete reversal of the electrical polarity at the amputation stump (Fig. 3). This change was not associated with any major change in the direct-current levels at other sites measured, except that the head voltages subsequently showed continuous fluctuation (wave forms lasting ten to fifteen seconds) during the period of recovery from anesthesia. These wave forms were found to be associated with any major damaging stimuli and, in this case, they probably represented the continuous stimulus from the amputation site. The

rapid reversal of electrical polarity at the site of amputation (with a shift from negative to positive voltage) may represent the cessation of direct-current electron flow in the associated nerve fibers. This cessation is a neural response to the trauma and does not necessitate sectioning of the nerve fibers themselves. It was noted that any stimulus producing cellular trauma—heat coagulation, radiation, freezing, fracture of the long bone of an extremity, or crush injury—produced a similar polarity shift, obviously without nerve section. The duration of the direct-

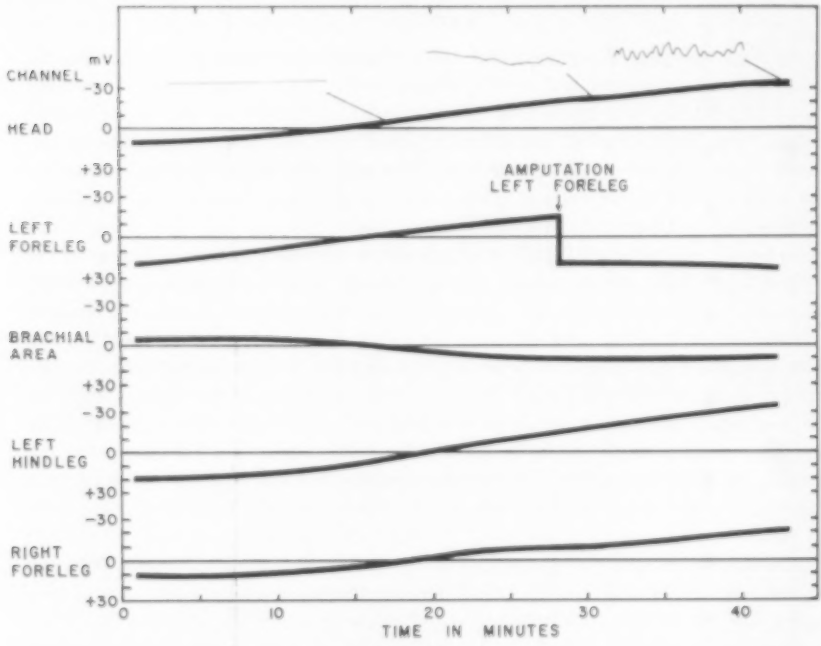

FIG. 3

Direct-current voltages monitored at five sites before and immediately after amputation of the left foreleg. During deep anesthesia (at left, on the time scale) a reversal of normal field pattern is present, with the extremities positive and the central areas negative to some degree. As anesthesia decreases, the voltages swing back through zero to normal polarities and potentials. Amputation of the left foreleg in this stage produces an immediate, lasting reversal of polarity back to the same levels present during deep anesthesia. This positive voltage not only persists to the point of full awakening, but actually increases slightly in magnitude. This positive voltage in the left forelimb is accompanied by a tendency to reversal of polarity, represented by a slower rate of change, in the contralateral right foreleg. The left hind limb, however, shows a steady return to normal value.

The three lines immediately above the heavy line representing the head-channel voltage (top) refer to the wave-form patterns seen in this channel with a faster speed of the recording paper (one millimeter per second) and a higher amplification than was used in the scale represented here. In deep anesthesia there is little or no wave-form pattern at this amplification; after amputation, however, continuous wave forms appear and increase in amplitude with time. These are the wave forms typical of the response to trauma; they actually represent variations in direct current since they have frequency periods ranging from five to twenty seconds. In this case, they apparently represent the response to the continuous trauma arising from the amputation.

current response appeared to be dependent upon the degree of trauma. At present, we can only speculate on the mechanism relating the cellular or tissue trauma to the changes in the bioelectric field itself. It is apparent that the trauma must be sensed in some way by the system to bring about a change in the direct-current activity of the appropriate cellular aggregate (brachial or lumbar). It has been known for some time that trauma involving cellular disruption causes a local "current of injury"[8]. Possibly, this is the local mechanism that influences the direct-current activity of the central nervous system. That there is some rela-

tionship between the peripheral nerve and the injury potential is evidenced by the decreased current of injury elicited from chronically denervated structures [28].

Section Two

The sequence of changes in the bioelectric field during the healing processes in regenerating forms was very different from the field-change sequence in non-regenerating animals. In the former group, a complex series of potential changes occurred that correlated well with the various stages of the regenerative process (Fig. 4). The initial positive polarity fell rapidly in value during the first two to three days, rose again during the fourth to sixth days to a value of about 50 per

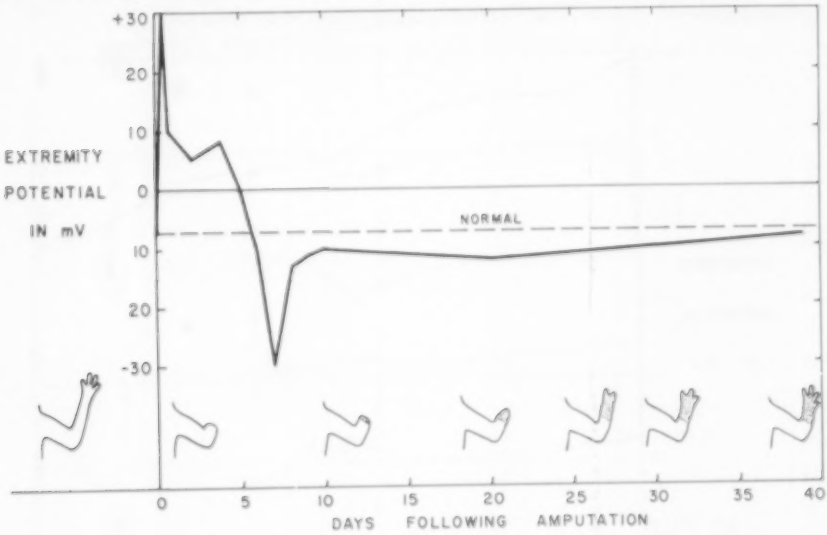

FIG. 4

The voltage changes in an extremity of a salamander during regeneration after amputation. The zero point on the horizontal scale immediately precedes amputation, which is concurrent with the very high positive peak in the voltage curve. The secondary positive peak in this case is on the fifth day and the negative maximum is on the eighth day. This negative bias of the regenerating limb is maintained until regeneration is complete. The normal limb voltage is about ten millivolts negative (interrupted line). The lower figures show schematically the stages of regeneration, which in this case was practically completed by the thirty-eighth to fortieth day.

cent of the initial, and then fell, crossing the zero line sometime between the fifth and tenth day. This was followed by a prompt negative shift of high amplitude, with maximum negativity occurring somewhere between the eighth and the fifteenth day. This negative polarization was very high, exceeding in millivoltage both the normal limb negativity and the post-traumatic positivity. This negative polarity remained elevated during the phase of axial growth and differentiation, and as late as the fortieth day after amputation the now almost completely regenerated extremity was still more negative than all the others in more than 50 per cent of the animals. This experiment involved a group of fourteen animals and, except for minor differences in the amplitude of the voltages, they all followed the same sequence of changes.

The anatomical and histological changes during the regenerative process are divided arbitrarily into two phases. Initially, there is the accumulation, at the site of amputation, of a mass of undifferentiated cells. The origin of these cells seems to be somewhat in doubt, although certain quantitative measurements have

recently indicated that they are derived from remaining tissue of the limb and that there is a movement of cells from the proximal tissues into the stump [7]. This undifferentiated cell mass is known as the blastema. It increases in size without evidence of differentiation until sometime about twenty to twenty-five days after amputation (in the adult), when it begins to show axial growth and differentiation and enters the second phase. The observed time course of the voltage-change sequence suggests that the initial positive polarity may be associated with relatively non-specific healing processes or with the blastema formation, whereas the negative polarity appears to be definitely associated with the differentiation growth phase. It was noted that those species and individuals which naturally have a slower rate of regeneration showed a correspondingly slower rate of electrical potential change; that is, the two processes were time related.

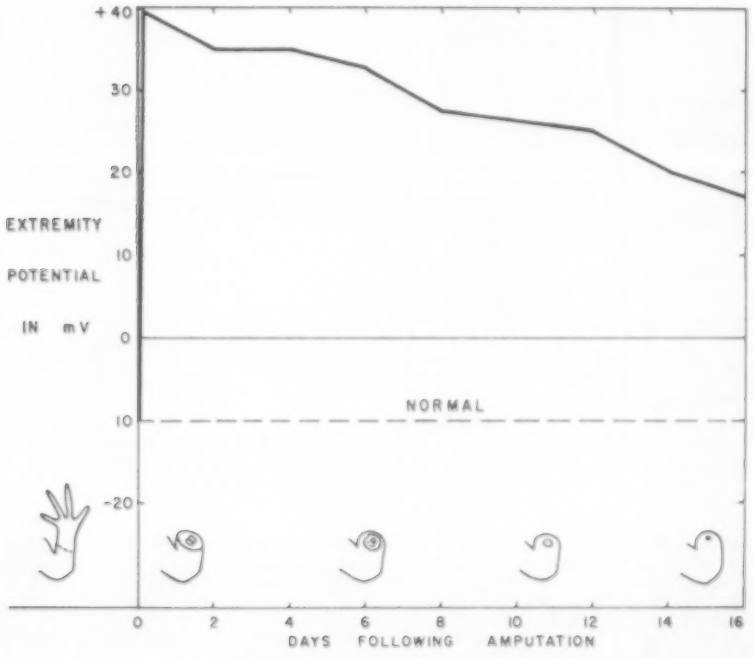

FIG. 5

Voltage changes during the healing process following amputation of the forelimb of a frog (a non-regenerating form). The zero point on the horizontal scale immediately precedes amputation, which is again concurrent with the very high positive polarity. Unlike the salamander (Fig. 4) this high positive polarity is maintained for a long period, dropping slowly to nearly normal levels as healing progresses almost to completion. The normal field pattern in this animal is similar to that of the salamander, and the extremities are invariably negative during the last stages of recovery from anesthesia (interrupted line).

Although the non-regenerating forms demonstrated the same immediate electrical-polarity reversal following amputation, they did not show the same subsequent sequence of electrical-potential changes as the regenerating forms (Fig. 5). The highly positive potentials remained elevated and fell only slowly toward zero potential as healing occurred. Only when healing was complete did the extremity begin to show negative potential and then it was generally lower than normal in value for some days. It must be emphasized that not one of twenty-four specimens so examined showed even a transient shift to negative voltages until healing was completed.

The healing process in these frogs consisted in granulation tissue and scar formation with gradual epithelialization of the raw surface from the skin edges (essentially the same healing process as in man). These animals are related to the salamanders, and in the larval stages are themselves capable of complete limb regeneration. They lose this ability in the adult form. However, the adult frog can be made to regenerate a nearly complete limb by grafting extra, functioning neural tissue into the amputation stump [25]. This is interpreted in the light of Singer's other findings as indicating that the normal density of nerve tissue in the adult frog limb is below the level necessary to sustain regeneration. Electrical

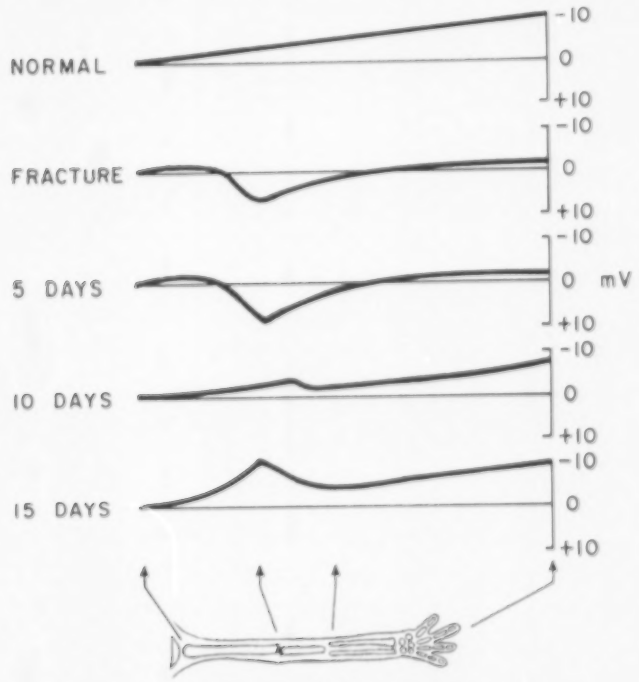

FIG. 6

Voltage changes observed during fracture healing. The simple fracture was produced at the junction of the lower and middle thirds of the humerus. The normal voltage gradient progressing peripherally along the limb is shown by the upper-line graph. This gradient is measured by placing the reference electrode over the brachial area and sweeping the recording electrode distally. Normally, there is a smooth curve of increasing negativity obtained by this method.

The lower four graphs show the disturbances in the limb-voltage gradient induced by the fracture at the times indicated. The sequence of local voltage changes is similar to that shown by the total extremity during regeneration (Fig. 4).

field measurements on intact frogs demonstrated a direct-current field pattern similar to that of the salamander, having the same spatial relationship to the anatomical arrangement of the central nervous system. Similarly, trauma caused the same polarity reversal in the potentials. However, the highly specific sequence of potential changes accompanying regeneration in the salamander did not occur in the non-regenerating frog. I have not had the opportunity to measure the potentials in a frog that was regenerating a limb secondary to nerve-grafting procedures, and attempts to drive the electrical potentials of the stump artificially in a regenerating sequence failed because of technical problems related to repeated anesthesia.

Section Three

After fracture of a long bone in the salamander, the same polarity reversal immediately appeared with a skin zone of positive potential around the area of the break. The subsequent voltage-change sequence during the healing of the fracture was similar to that appearing during limb regeneration, although somewhat lower in magnitude (Fig. 6). The difference in magnitude of the potential would appear to be related to the fact that the injured part is within the soft tissues and that it is situated along the normal limb voltage gradient. Thus far, no correlations have been made between various stages of the fracture-healing process and the voltage-change sequence, primarily because of the difficulty in obtaining good roentgenograms of these small extremities.

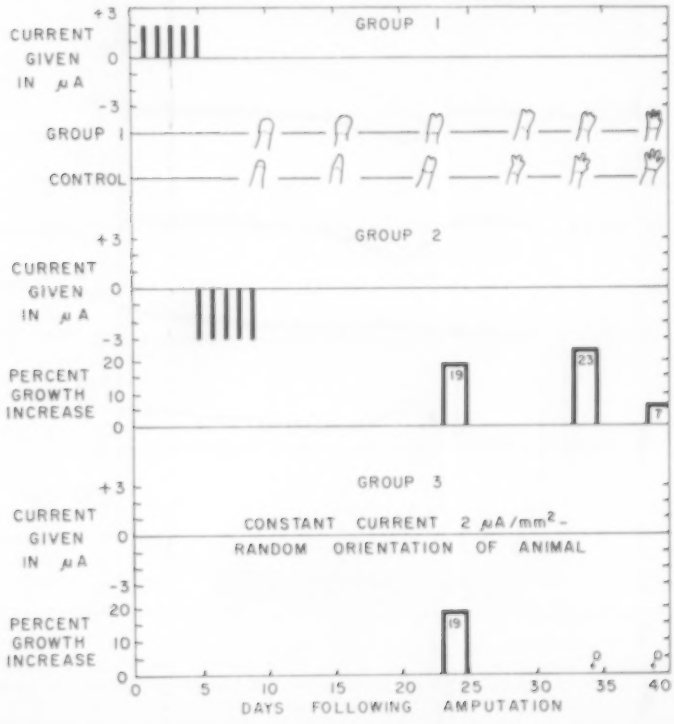

FIG. 7

The results of administration of current of various polarities to the regenerating forelimb of the salamander. The upper three lines (Group 1) refer to the series of animals given positive current during the first five days after amputation. The increase in blastema formation and the slower rate of re-differentiation in the experimental animals are schematically shown. The center two lines (Group 2) refer to the animals given negative current from the fifth to the ninth day inclusive (upper line). The percentage increase in axial growth of the experimental limbs over controls is shown on the lower line. A period of growth acceleration appeared to take place from the twentieth to the fortieth day, with a maximum acceleration about the thirty-fifth day (23 per cent). The lower portion (Group 3) refers to the animals exposed to constant current, with random orientation of the animal permitted. The solitary spurt in axial growth on the twenty-fourth day is thought to have been the result of changes in ionic strength in the tank. In Groups 2 and 3, all measurements were made with an ocular micrometer at five to ten-day intervals.

It is an apparently well accepted fact that fracture healing is a regenerative process [17]. This being the case, the observed regenerative type of voltage-change sequence is entirely appropriate. The relationship between the density of the peripheral nerves and the regenerative process was determined only in the case

of limb regeneration. What the relationship is in the case of fracture healing is a matter of speculation. As previously stated, neither injury to the nerve itself nor proliferation of the nerve fibers need be considered as prerequisites for the sequence of electrical-potential changes. Certainly, the fracture is productive of sufficient local currents of injury to inform the bioelectric field that such an event has transpired. The electrical-potential changes can be produced functionally by the appropriate cellular aggregate (brachial or lumbar) without such anatomical alterations.

Section Four

Three separate experiments were performed in which external current was administered to regenerating forms after amputation. In the first group, six larval salamanders were given two microamperes of current directly to the amputation stump for five to ten minutes per day for the first five postoperative days. This current was oriented so as to enhance the normally occurring positive polarity at that time. On the tenth to twelfth day, all six of these animals demonstrated a blastema almost twice as large as that noted in a simultaneous control group. It was difficult to quantitate these differences since the blastema is three-dimensional and so small that it does not lend itself to precise measurement. An observation of equal importance to the increased size of the blastema was the subsequent retardation of regeneration in the phase of axial growth and differentiation. In all of the control group there developed initial digitation of the regenerate on the sixteenth day, whereas the experimental group did not reach this stage until four to six days later. These results are summarized in Figure 7, upper section.

In the second experiment, six adult animals were given three microamperes of current directly to the amputation stump for five to ten minutes per day from the fifth to the tenth day. This current was oriented to enhance the normally occurring negative polarization at that time. There was no discernible difference in blastema formation compared with a simultaneous control group; however, subsequent axial growth, as measured by ocular micrometer at intervals of five to six days, exceeded that of the control group by significant amounts (Fig. 7, center section). The comparisons of growth rate were made by measuring by ocular micrometer the length of the regenerated limb in the six experimental and six control animals. The average results in each group were determined, and the average percentage increase in axial growth of the experimental animals over the controls was calculated at different time intervals. It was noted that all of the experimental animals showed a greater length of regenerate compared with the most rapidly growing control animal. The total size of the regenerates, however, was small; a 25 per cent difference refers to less than one millimeter in actual length.

Digitation, as an index of differentiation, also appeared to be accelerated in the experimental group, but this observation was difficult to quantitate. The technical difficulties encountered in this experiment necessitated that small numbers of animals be utilized. However, despite the lack of a statistically significant sample, the consistency of the results observed suggest that some growth-accelerating effect was obtained. In the animals receiving positive polarity current from the first to the fifth day after amputation, an increase in tissue resistance was noted on the third day, necessitating twice the previous voltage to deliver the same amount of current. The same phenomenon was noted on the eighth day in the series receiving negative polarity current from the fifth to the tenth day. In each case, current of the opposite polarity was easily passed, which would appear to indicate that there was some rectifier type of mechanism in the tissues. The significance of these observations is not known.

A third group of six salamanders were taken on the first day after amputation and placed in a standard aquarium which had a steady direct electrical current flowing through the water in one direction. The current density was regulated to produce two microamperes per square millimeter, and the animals were permitted to assume random orientation in respect to the direction of current flow. There were no changes in the rate of regeneration in this group except for a solitary, but striking, increase of about 19 per cent on the twenty-fourth to twenty-fifth day of measurement (Fig. 7, lower section). Subsequent measurements showed no significant changes in rate, and the group completed regeneration at about the same time as the control group. In reviewing the experimental records, it was noted that two days prior to the twenty-fourth day the water in the tank was supplemented. Since Kappers observed some time ago that the trophic responses of aquatic organisms to direct-current fields depended upon ionic concentration, similar factors are presumed to have been in action here. To evaluate properly this random-orientation-steady-current study, strict control over ionic parameters would be necessary.

Since completing these experiments, it has come to my attention that an experiment, similar to the last one described, was done with large numbers of animals by Frazee in 1909. He reported a statistically significant increase in the rate of regeneration when direct current was passed through tanks housing larval salamanders with amputated limbs. The techniques available at that time were insufficient to indicate the current density, and knowledge of the bioelectric field was fragmentary. These results therefore could not then be interpreted in any satisfactory frame of reference. It is of interest to note that Frazee had traced similar experimental attempts to influence the rate of regeneration by electrical means as far back as 1840 [22].

DISCUSSION

Growth processes are not only complex in nature but cover a continuous spectrum of abilities and potentials. Whether one is considering the embryonic growth of an entire organism from a single fertilized ovum or the simple closure of a skin defect by epithelial proliferation, the process is quite evidently under precise control. Tumor and keloid formation are usually cited as evidence of loss or disturbance of the control mechanisms. Whether or not the same mechanisms are operative in all of these conditions can only be speculated upon at this time in view of the extreme paucity of information.

Philosophically, the phenomenon of growth is such a basic process that one would expect that exceedingly primitive control mechanisms are operative and that all of these processes bear some interrelationship. The aforementioned work of Singer, establishing the relationship between the peripheral nerves and limb regeneration, is an important beginning. However, this neural effect should not be interpreted as involving any of the known functions of the nervous system. Since any type of nerve tissue is equally potent, such known parameters as the action potential cannot be involved. It appears more likely that some very basic property of the nervous system, or its associated tissues, is the controlling mechanism. From the evidence presented in this paper, the thesis is proposed that the direct-current activity of some portion of the central nervous system constitutes a true data transmission and control system and that one of the output parameters of the system is the control of the growth processes involved in regeneration and repair. Since the electrical-field activity is not related to the system that produced action potentials and may even be a function of such tissues as the Schwann-cell syncytium, the observation that any type of nerve tissue will bring

about regeneration becomes more logical. There must exist certain linkage mechanisms between the cells of the organism and the bioelectric field itself, both in an input or sensory fashion and as an output or control mechanism. Considering system inputs, the relationships demonstrated between trauma and the changes in the field potentials appear to be mediated by the current of injury generated at the cellular level. Regarding outputs of the system, the influence of a steady-state direct-current potential on cells has been previously demonstrated in the central nervous system [26]. In this case the rhythmic activity (as action potentials) of cortical neurons can be modulated by changing the direct-current level existing in the environment of the neurons. More recently, it was demonstrated that cells of a regenerating tissue have electrical charges that are different from cells of the same tissue in its normal state [3]. An environmental parameter for all cells of the organism is the direct-current or bioelectric field potential generated in their area. This field could influence the site of an injury so as to cause accumulation of cell types bearing specific electrical charges at points having specific electrical potentials. In this fashion, the output portion of the direct-current field system can be linked to cells, and a true closed loop, data transmission and control system, is established for the growth process.

The preliminary nature of these experiments must be stressed. In all probability, the electrical field changes accompanying growth and healing processes are much more complicated (both temporally and spatially) than are reported here. Nevertheless, it would appear that certain specific alterations in the bioelectric field accompany the process of regeneration and that these alterations do not appear in the case of less adequate healing processes. It is surprising that the application of intermittent electrical currents produced an acceleration in the regenerative process. If the field potentials are the control mechanism, they must be considered to be operative in a continuous fashion. In these experiments, it must be assumed that the observed alterations were produced in an animal which normally has the capacity to regenerate an extremity, and that the added potentials in this case reinforced those which were naturally occurring. Although it would appear that continuous currents would have to be applied to reverse natural potentials, the successful attempt to inhibit malignant-tumor growth by intermittent field reversals must be noted [12].

The application of similar techniques to the study and control of growth processes in man requires much more investigation both in animals and in human beings. Only recently has a technique been evolved permitting the precise measurement of the direct-current field in the human being[1]. Initial measurements indicated the presence of a human field system similar to that of the salamander, bearing the same spatial relationships to the central nervous system. Anesthesia was found to produce a similar tendency toward reversal of the field potentials. However, the cranial portions of the bioelectric field in man show a much greater complexity than in animals, apparently being influenced by the emotions and sensory inputs. Despite this, the general relationship between the human and the amphibian bioelectric field are remarkably similar.

In summary, bioelectric direct-current potentials have been shown to constitute an organized data transmission and control system. Relationships indicating some control function have been established between the direct-current field and the process of limb regeneration.

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Comminuted Colles' Fractures

Evaluation of a Method of Treatment

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A study of the end results of a method for treatment of comminuted Colles' fractures is presented to bring up to date our experience with the management of this fracture after almost a decade.

In a previous study at Jefferson Medical College Hospital of Philadelphia [5], it was suggested that methods commonly in use for treatment of this fracture gave functional results that "were not felt to be very commendable", and that improved anatomical restoration would lead to improved function. Accordingly, a new method of management, designed to improve the quality of both reduction and immobilization, was introduced. A favorable preliminary report was published in 1952 [6], along with anatomical studies substantiating the rationale for the method.

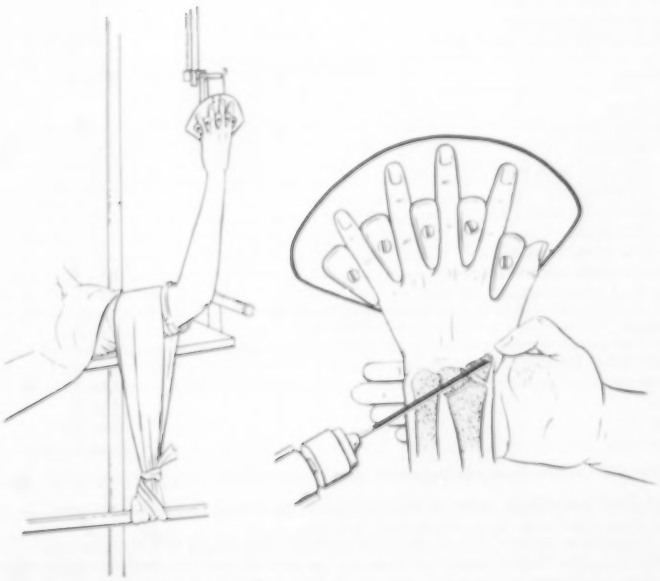


Fig. 1

Traction and countertraction are applied using the Weinberger traction apparatus and a fracture table. As the Steinmann pin is inserted, the wrist is pronated and an assistant pushes dorsalward at the fracture site to help maintain the palmar angulation of the distal radial articular surface. With his thumb, the assistant indicates the location of the radial styloid process and thus helps the surgeon to direct the pin.

Essentially, the method (Fig. 1) is a form of internal skeletal fixation using the intact ulna as a fixation point through which a threaded Steinmann pin (7/64 of an inch in diameter) is obliquely directed and advanced until the radial styloid process is impaled and held in the reduced position which has been achieved

TABLE I

POINT SYSTEM USED TO EVALUATE END RESULTS OF HEALED COLLES' FRACTURES *

Result	Points
Residual Deformity	
Prominent ulnar styloid	1
Residual dorsal tilt	2
Radial deviation of hand	2 to 3
Point Range	0 to 3
Subjective Evaluation	
Excellent—No pain, disability, or limitation of motion	0
Good—Occasional pain, slight limitation of motion, no disability	2
Fair—Occasional pain, slight limitation of motion, feeling of weakness in wrist, no particular disability if careful, activities slightly restricted.	4
Poor—Pain, limitation of motion, disability, activities more or less markedly restricted	6
Point Range	0 to 6
Objective Evaluation †	
Loss of dorsiflexion	5
Loss of ulnar deviation	3
Loss of supination	2
Loss of palmar flexion	1
Loss of radial deviation	1
Loss of circumduction	1
Pain in distal radio-ulnar joint	1
Point Range	0 to 5
Complications	
Arthritic Change	
Minimal	1
Minimal with pain	3
Moderate	2
Moderate with pain	4
Severe	3
Severe with pain	5
Nerve complications (median)	1 to 3
Poor finger function due to cast	1 to 2
Point Range	0 to 5
End-result Point Ranges	
Excellent	0 to 2
Good	3 to 8
Poor	9 to 20
Fair	21 and above

*Reprinted from Evaluation of Healed Colles' Fractures. By J. J. Gartland, Jr., and C. W. Werley. J. Bone and Joint Surg., **33-A:** 900, Oct. 1951.

† The objective evaluation is based upon the following ranges of motion as being the minimum for normal function: dorsiflexion, 45 degrees; palmar flexion, 30 degrees; radial deviation, 15 degrees; ulnar deviation, 15 degrees; pronation, 50 degrees; and supination, 50 degrees.

before insertion of the pin by the Weinberger traction apparatus. After the pin is in place, it is cut off beneath the skin. The position of the pin is such that the comminuted fragments are maintained in the reduced position by the taut envelope of wrist ligaments that encompass the fragments. The tension in the ligaments is maintained by the pin much as a tent pole supports the roof of a pyramidal tent. The method is similar in principle to the various pins-in-plaster techniques reported [9,11,12,14,18], but avoids the hazard of metallic fixation protruding through the skin or entering a portion of the extremity other than the site

of the fracture. A long arm plaster cast is applied and the internal fixation device is left in place until there is roentgenographic evidence of callus (a minimum of eight weeks). The device is then removed, under local anesthesia, through a small skin incision. No roentgenographic or flouroscopic control was available or used for the reduction or insertion of the Steinmann pin in the present series.

MATERIAL AND METHOD OF STUDY

Although this method was not used exclusively in all Colles' fractures during the period covered by this study, it was found that from the time of the introduction of this method to the time of this study, a total of 189 fractures had been

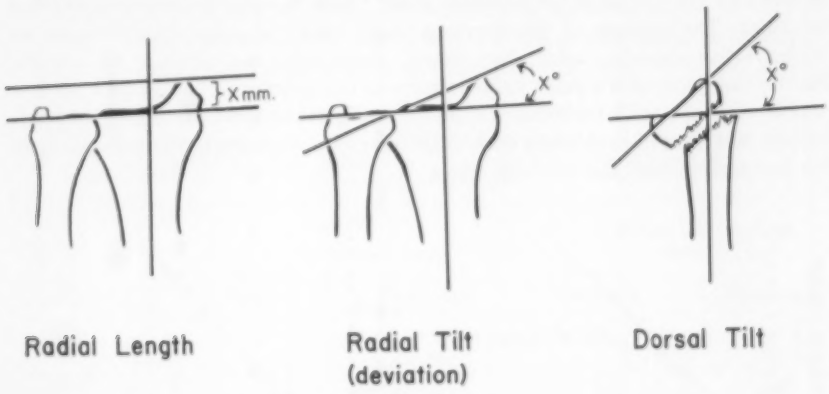


FIG. 2

Method of measuring radial length, radial tilt, and dorsal tilt. A reference line is drawn along the central longitudinal axis of the radius on both anteroposterior and lateral roentgenograms.

To determine radial length, two lines perpendicular to the center line of the radius are drawn on the anteroposterior roentgenogram: one at the level of the distal end of the ulna not including the ulnar styloid process; the other at the level of the tip of the radial styloid. The perpendicular distance between these two parallel lines measured in millimeters (X mm.) is the radial length.

To determine the radial tilt, a line perpendicular to the center line of the radius is drawn on the anteroposterior roentgenogram at the level of the distal end of the ulna not including the ulnar styloid process; another line is drawn through the ulnar and radial margins of the radial articular surface. The angle (X°) formed by these two lines is the radial tilt.

To determine volar-dorsal tilt, one line is drawn perpendicular to the center line of the radius on the lateral roentgenogram in the region of the fracture and another line is drawn parallel to the distal radial articular surface. The angle (X°) formed by these two lines is the volar-dorsal tilt. The tilt was recorded as 0 degree if the radial articular surface was parallel to the perpendicular line, a + angle if the articular surface showed a volar tilt, and a −angle if there was a dorsal tilt.

treated in this way by all members of the staff. All of the fractures selected were comminuted and the majority extended into the radiocarpal joint. We were able to obtain current follow-up studies on fifty patients, one of whom had had fractures of both wrists treated in this way, making a total of fifty-one fractures. Original roentgenograms were available in thirty-eight fractures, all of which showed extensive comminution. The patients studied were typical of patients with this injury in that they were predominantly women and their average age was 55.7 years. The length of follow-up varied from nine months to 121 months and averaged 58.4 months.

The fifty patients were examined personally, and the history of their fractures was reviewed. The patient's opinion of the result was solicited, generally, by detailed questions regarding specific activities, such as turning door knobs, opening screw-type bottles, buttoning, ironing, and similar household duties. Subjective observation of deformity was made as well as objective measurements of the girth of the wrist. Goniometer measurement of all ranges of motion of both

wrists was obtained, the strength of grip and the sensation were tested, and the function of tendons was also assessed.

In addition, roentgenograms were used to obtain a more precisely measurable index of residual deformity. Anteroposterior and lateral roentgenograms were made of both wrists with a carefully standardized technique to rule out any distortion which might invalidate comparison of the two wrists. Measurements were then made of the volar-dorsal tilt, radial tilt, and radial length of both the affected and the normal wrists by the methods illustrated in Figure 2.

First, in order to find out if any improvement had resulted from the application of the new method, we felt it desirable to assess the functional results exactly as this had been done in the previous study [8] and to compare the two series of fractures. The authors of the previous study used "a point system based on authoritative disability evaluation charts, which takes into account all possible factors and gives each a point value relative to one another". This point system is explained in the table reproduced from their original article (Table I). This point system was used in evaluating each of the fifty-one fractures in the present series for comparison with the previous series.

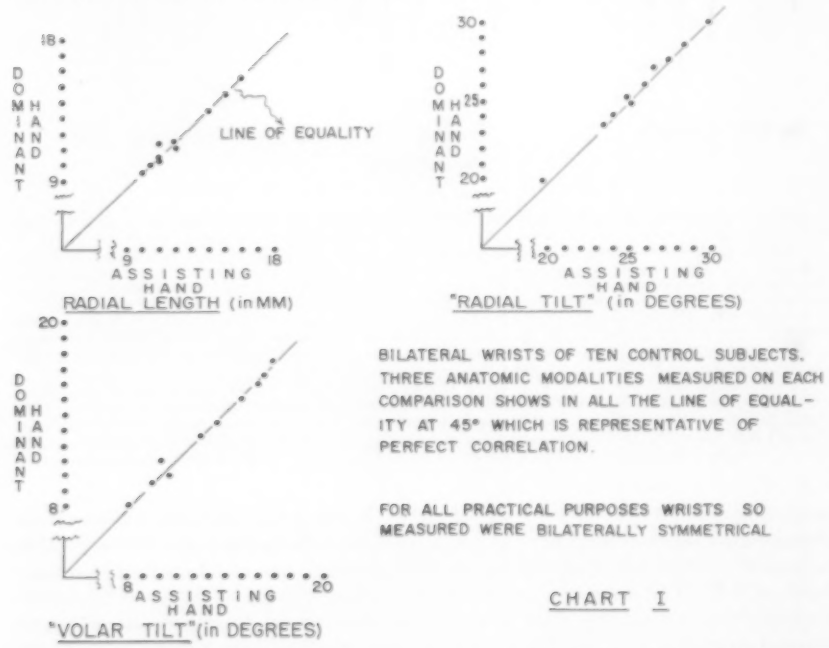

DOMINANT HAND
LINE OF EQUALITY
ASSISTING HAND
RADIAL LENGTH (in MM)
"RADIAL TILT" (in DEGREES)
"VOLAR TILT" (in DEGREES)
BILATERAL WRISTS OF TEN CONTROL SUBJECTS. THREE ANATOMIC MODALITIES MEASURED ON EACH COMPARISON SHOWS IN ALL THE LINE OF EQUALITY AT 45° WHICH IS REPRESENTATIVE OF PERFECT CORRELATION.
FOR ALL PRACTICAL PURPOSES WRISTS SO MEASURED WERE BILATERALLY SYMMETRICAL

CHART I

Second, because in spite of the attempt at objectivity of the point-range system, we felt that a considerable amount of interpretation on the part of the examiner was necessary in its use, we adopted a different functional rating based on evaluation of loss of motion for our comparison with the anatomic result. This method of functional rating, we believe, has the virtues of being completely objective as well as conforming to more recently published standards of disability evaluation [5]. These standards were drawn up by a special committee on medical rating of physical impairment of the American Medical Association and published in a special edition of the Journal of the American Medical Asso-

ciation [5]. This publication expressed in table form the possible losses of motion in increments of ten degrees for each motion of each joint of the extremity with the corresponding percentage of impairment expressed in terms of impairment of the upper extremity brought about by such loss of motion. Thus, it is possible to determine, for instance, the amount of palmar flexion lost at the wrist and read directly from the official table the percentage that this impairs the upper extremity in the opinion of the experts who drew up the standards. To complete the total impairment due to injury of the wrist, it is necessary to calculate the loss for each of the six separate motions possible: flexion, extension, radial deviation, ulnar deviation, supination, and pronation as measured by goniometer, and combine them to achieve the total percentage of impairment of the wrist motion as related to function of the upper extremity. By subtracting this percentage of impairment from 100, we arrived at a percentage of restoration of function of the upper

TABLE II

COMPARISON OF FUNCTIONAL RESULTS IN CURRENT SERIES WITH THOSE OF GARTLAND AND WERLEY

	Current Series		Gartland and Werley Series	
End-results	No. of Fractures	Percentage	No. of Fractures	Percentage
Excellent	24	84	13	69
Good	19		28	
Fair	8	16	17	28
Poor	0	0	2	3
Total	51	Total	60	

extremity which will be used when the result is discussed. This method of evaluation was used in the assessment of forty-three patients whose opposite wrist had never been injured. In these patients, we could obtain the anatomical measurement of the normal and affected wrist, as well as the measurements of the range of motion of the normal and affected wrist. Thus, we had a living example both anatomically and functionally against which to measure restoration of function. It is stated in the guide to evaluation of permanent impairment of the extremities and back that "whenever possible, contralateral normal joints should serve as the standard against which the impaired joint is measured" [5]. To make sure that the anatomical measurements used are normally equal in both wrists, we studied ten controls. The results of this study, as shown in Chart I, indicate that normally these measurements are strictly comparable.

RESULTS

Comparing the functional results of these fractures with those of the fractures reviewed in the previous study from this hospital [8], it can be seen (Table II) that the total number of acceptable results (excellent or good) is increased from 69 to 84 per cent in this series. It can also be seen that there were no poor results by the current method. These more favorable results in the present series, it should be emphasized, were obtained in fractures which were all comminuted, whereas only 88 per cent of those in the earlier series were comminuted.

In thirty-eight of the fractures original roentgenograms were available. These were subgrouped according to whether or not there was involvement of the

TABLE III

END RESULTS IN THIRTY-EIGHT FRACTURES *

End Results	Group I No. of Fractures	Group II No. of Fractures	Group III No. of Fractures
Excellent	9	2	8
Good	1	1	11
Fair	2	0	4
Poor	0	0	0
Totals	12	3	23

* Group I: comminuted, but not into radiocarpal joint;
Group II: into joint without displacement; and
Group III: into joint with displacement.

radial articular surface and it was found (Table III) that the results were excellent in nine (75 per cent) of twelve fractures with no involvement of the radial articular surface, whereas only ten (62 per cent) of the twenty-six fractures with involvement of the joint surface had excellent results. However, when the good and excellent results are combined there is little difference. In the fractures without joint involvement, 83 per cent were good or excellent; in the fractures involving the joint surface, 84 per cent were good or excellent.

The second method of determining functional results, one which we felt was purely objective, as previously described, showed that in this series of forty-three patients, the average restoration of function was 93.3 per cent (and ranged from a low of 80 per cent in one patient to perfection in three). One-half of the cases were rated 95 per cent or better; only 16 per cent were less than 90 per cent of normal.

Measured by the method described (Fig. 2), restoration of radial length averaged 78 per cent for the series. Radial length was restored 100 per cent in three patients, and in nine the radial length was greater than the normal. However, four patients showed poor restoration of length: 33 per cent, 33 per cent, 35 per cent, and 17 per cent, respectively. It was rather startling to find, however, when a correlation was attempted of this particular anatomical characteristic with the functional results, that there was no strictly linear relationship except in the extremely good and extremely bad results.

The average restoration of radial tilt was to 84 per cent of normal. In seven radii, 100 per cent restoration was achieved; the lowest figure was 56 per cent of the normal. Radial tilt and radial length seem to be closely correlated, although not absolutely. Five of the twelve wrists with 100 per cent restoration of length, or greater than the normal radial length, also had complete restoration of tilt. Two of the four wrists with very poor restoration of length also had poor restoration of tilt but the other two had good restoration of tilt. The correlation between restoration of radial tilt alone and the functional result, as was the case with radial length, was not definite.

The dorsal-volar tilt is normally a variable anatomical characteristic. In the opposite normal wrist, the tilt varied from −7 degrees (dorsal tilt) to +19 degrees (volar tilt). It was restored to normal or to more than normal palmar angulation in sixteen of the forty-three wrists (37 per cent). The average residuum of dorsal tilt was −13 degrees. It was not possible to express the results in the correction of dorsal tilt as percentages since the baseline is too variable. In the thirty-eight fractures with original roentgenograms, this element of deformity

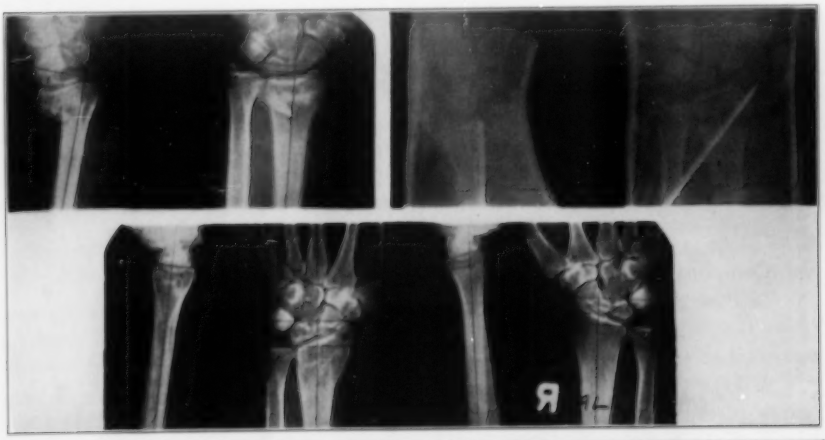
TABLE IV

TWELVE FUNCTIONAL RESULTS WITH THEIR ANATOMICAL RESTORATIONS

	Six Best Functional Results					
	100	100	100	99	98	98
Radial length (*per cent*)	100	35	100	86	75	100
Radial tilt (*per cent*)	83	83	100	63	88	96
Volar-dorsal tilt (*degrees*)	−13.5	+0.5	−4	−0.5	0	−0.5
	Six Worst Functional Results					
	80	81	85	85	85	87
Radial length (*per cent*)	17	92	73	100	77	33
Radial tilt (*per cent*)	68	88	63	88	100	86
Volar-dorsal tilt (*degrees*)	−9.5	−19	−27.5	−25	−16.5	−46.5

was changed from an average original tilt of −24 degrees to an average residual tilt of −10 degrees. There was no more correlation of the degree of correction of this anatomical characteristic alone with the functional end result than there was with the other two characteristics previously discussed.

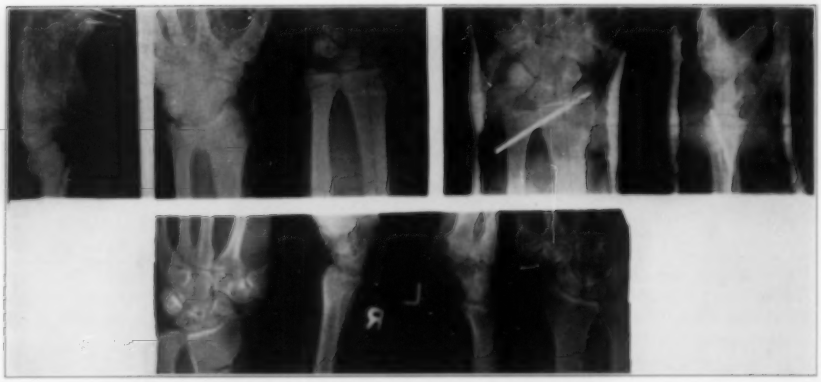
Because no one anatomical characteristic seemed to stand out as obviously associated with good or poor functional results, the three anatomical variables were combined and correlated with the functional results. Even then, there was no correlation except in the extremely good or extremely bad results. If the six worst functional results (all of which were less than 90 per cent restored) are compared with the six best (all of which were 98 per cent or more restored) it is noted (Table IV) that in the poor results all the anatomical measurements are low except in two instances—one with 100 per cent restoration of radial length;



ANATOMIC									FUNCT.
DORSAL TILT			RADIAL TILT			RADIAL LENGTH			% RESTORAT.
ORIG.	RESID.	OPP.	ORIG.	RESID.	OPP.	ORIG.	RESID.	OPP.	
-21	0	14.5	13	28.5	29.5	3	13	13.5	95%

FIG. 3

Roentgenograms of a properly treated fracture with an excellent result. The original roentgenograms are in the upper left-hand corner; those made after reduction and fixation, in the upper right. The roentgenograms made thirty-nine months after treatment are at the bottom left. The normal hand is at the bottom right.



ANATOMIC									FUNCT.
DORSAL TILT			RADIAL TILT			RADIAL LENGTH			% RESTORAT.
ORIG.	RESID.	OPP.	ORIG.	RESID.	OPP.	ORIG.	RESID.	OPP.	
-28.	8	16	18	28	23	8	12	10.5	96%

FIG. 4

Roentgenograms of a fracture with an excellent result in which greater than normal radial length and radial tilt were produced, whereas the dorsal tilt was not restored completely. The original roentgenograms (upper left) show a comminuted transverse fracture not involving the joint surface. A good reduction and satisfactory placement of the pin were achieved (upper right). The result forty-two months after fracture (lower left) is compared with the normal wrist (lower right).

the other with 100 per cent restoration of radial tilt—and restoration of dorsal tilt is especially poor. On the other hand, in the excellent results there are only two measurements that are very poor—one, a 35 per cent restoration of radial length; the other, a residual dorsal tilt of −13.5 degrees. In general, in the excellent results the dorsal tilt is better restored, and in the wrists where one anatomical element is poorly restored the others tend to be average or above. Representative cases are shown in Figures 3 through 6.

COMPLICATIONS

Complications attributable to the method itself were:

1. Poor placement of the pin requiring replacement in seven of the fractures. (Here it should be restated that neither roentgenographic nor flouroscopic control was used in any of the cases studied.)

2. Less than optimum position of the pin in fifteen wrists, as judged by a review of the original postoperative roentgenograms, and by the fact that some length of the radius was lost while the pin was still in place.

3. Loss of reduction in seven wrists when the pin was removed before eight weeks had elapsed.

4. Breakage of the pin in two wrists (in both of which the pin was bent at the time of insertion and in both of which the caliber of the pin was smaller than 7/64 of an inch. These were both early cases in the series and led to the adoption of the larger caliber threaded Steinmann pin in all procedures done since 1954.)

Complications considered to be related to external immobilization and possible occurrences with any form of treatment for Colles' fracture were:

1. Mild flexion contracture of the fifth metacarpophalangeal joint in five patients;

ANATOMIC									FUNCT.
DORSAL TILT			RADIAL TILT			RADIAL LENGTH			% RESTORAT.
ORIG.	RESID.	OPP.	ORIG.	RESID.	OPP.	ORIG.	RESID.	OPP.	
-16	-31	+9	8	21.5	25	-6	3.5	10.5	87%

FIG. 5

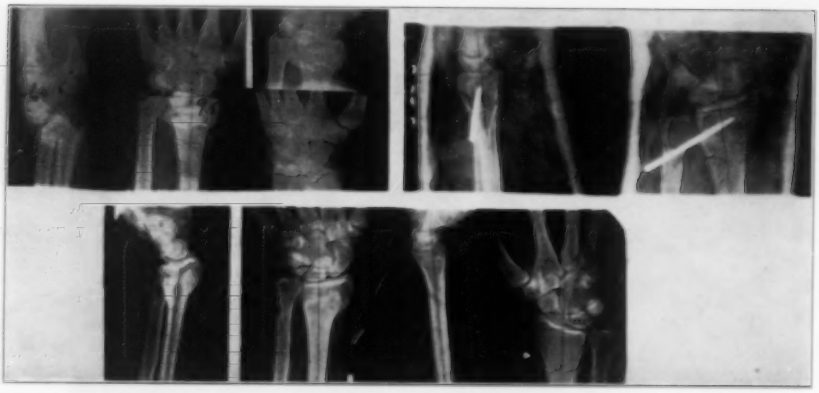
Roentgenograms showing a poor anatomical result in a wrist with a poor functional result. The original roentgenograms (top) show severe shortening with loss of radial and volar tilt. The roentgenograms made after reduction (middle) show poor placement of the pin and incomplete reduction of the fracture. The pin was removed four weeks after insertion because it was in the radiocarpal joint. The anatomical result at twenty-five months (lower right) can be compared with the normal wrist (lower left). The poor anatomical result would appear to explain the poor functional result in this instance.

2. Residual traumatic arthritis of the wrist as seen in roentgenograms in three patients;

3. Sympathetic dystrophy in one.

DISCUSSION

Published opinions on the results of treatment of Colles' fracture are heavily in favor of the view that there is much room for improvement [1,2,3,7,9,11,12,13,14,15,16,17,18,22,23,24,25,26,27,28,29], although a few authors dissent [4,19,20], claiming 95 or 96 per cent excellent or good functional results despite a much lower percentage of good anatomical restoration. Abraham Colles himself is quoted in support of the latter



ANATOMIC									FUNCT.
DORSAL TILT			RADIAL TILT			RADIAL LENGTH			% RESTORAT.
ORIG.	RESID.	OPP.	ORIG.	RESID.	OPP.	ORIG.	RESID.	OPP.	
-60	-23.5	12	9.5	14	22.5	3	3	9	94%

FIG. 6

Roentgenograms of a wrist with a reasonably good functional result and the worst anatomical results in the series. The original roentgenograms (upper left) show comminution and shortening. After reduction and fixation (upper right), it is apparent that the pin is too short, failing to reach the radial styloid process. The pin must impale the radial styloid process if it is to hold the rest of the fragments in place. The final roentgenograms (lower left), made seventy-one months post reduction, show a poor anatomical result as seen by comparison with the normal wrist (lower right).

opinion [19]. Nevertheless, where statistics are given in carefully analyzed series, the incidence of unsatisfactory end results is as high as 31.7 per cent [5], 17.3 per cent [13], 24 per cent [14], and 49 per cent [29], but these results are based on somewhat differing criteria.

The concern of many surgeons, occasioned by the poor results after treatment of this fracture, is also manifested by published recommendations for some form of skeletal fixation to maintain reduction [3,9,10,11,12,14,18], although some have been reluctant to use pins, especially through the metacarpals, because of the danger of infection or fibrosis [7]. The method of skeletal fixation used in this series produced no infections in the patients returning for follow-up or, to our knowledge, in any patient seen in the routine short-range follow-up carried out in our fracture clinic.

The functional results, which we believe to be based on extremely rigid criteria, show an improvement over previously reported end-result studies done with equal care and objectivity.

The fractures treated by this method correspond to what other observers have called complicated or unstable fractures. Many of these reveal the true amount of comminution that has taken place only on roentgenograms made after reduction, when good length has been restored by traction. These fractures are comparable, as has been pointed out before [19], to comminuted fractures of the vertebrae or the calcaneus; they require special consideration. Continuous skeletal traction by some means seems to be the best insurance against loss of reduction. The method used in this series, although perhaps not so simple as others recommended, confines the non-protruding metallic fixation to the area of fracture and

allows easy, full, and painless range of all fingers throughout the period of immobilization. The fear of interference with pronation and supination expressed [7] after the preliminary report on this method has not proved to be well founded in this long-term follow-up study.

Since the anatomical results by our method of assessment are dependent on the combined adequacy of reduction and the adequacy of immobilization, we reviewed all the fractures with a full series of roentgenograms in an effort to determine when, during the course of treatment, loss of position occurred. Without exception, we found that when there was a loss of initial reduction the fracture was one of those listed under complications; that is, the pin placement was poor, the pin was of inadequate caliber (which resulted in bending and breaking in two cases), or the pin had been removed in less than eight weeks. On the other hand, we found that when loss of original reduction was minor or nil, the pin invariably had been placed or replaced in good position and had been removed after eight weeks or more. The method, as described, is simple to carry out, but necessitates meticulous placement of the proper size of pin and a minimum of eight weeks of such fixation for success. The number of imperfect placements and the necessity for replacements recounted suggests that roentgenographic check at the time of insertion of the pin would increase the number of successful outcomes.

In previous studies there has been a tendency to blame one element of the classic displacement of a Colles' fracture for poor function [3,4,14,15,19,20].

Our study does not substantiate such opinions. Rather, our evaluation of the anatomical results in relation to function agrees more with Green and Gay's findings [13] that in the poor functional results there was inferior restoration of all the elements in the deformity: radial tilt, dorsal tilt, and radial length. Therefore, we believe that to achieve consistently excellent results, the reduction must correct all the elements of displacement and the position attained must be maintained by skeletal fixation for eight to ten weeks.

SUMMARY AND CONCLUSION

The long-term results of a method of treatment for comminuted Colles' fracture by closed reduction and internal fixation were studied. Both anatomical and functional end results were determined by rigid criteria and compared. Our conclusions were:

1. The method makes it possible to achieve, in severely comminuted Colles' fracture, excellent anatomical and functional results.

2. The anatomical and functional results do not correlate completely; however, outstandingly good anatomical restoration by this method invariably yields a fine functional result, whereas very poor anatomical results are associated with poor functional results.

3. The technique must be carried out with extreme care and accuracy in both placement of the pin and decision for time of removal.

4. This method, when employed skillfully, has advantages over other skeletal-fixation techniques in that no pin-tract infections have occurred and there can be no interference with function of the hand due to scarring in the metacarpal area.

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Enzyme Alterations in the Epiphyseal Plate of the Rabbit Resulting from Aminoacetonitrile Administration

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Administration of aminoacetonitrile and related compounds to animals undergoing rapid growth has been demonstrated to influence enchondral-bone formation profoundly [1,10,27,30,32,33,37]. The lesions produced in weanling rats and rabbits administered aminoacetonitrile, B-aminoproprionitrile, or *Lathyrus odoratus* seed diets are manifest after one week of treatment and characteristically involve the epiphyseal plate [27,30]. The width of the plate is increased; histologically, there is widening and disintegration of the hypertrophic cartilage-cell area, with derangement of cartilage calcification adjacent to the metaphysis [10,27,32]. The disturbances resulting from aminonitrile administration are not limited to enchondral-bone formation, however, as lesions have also been observed in the media of the aorta, the central nervous system, and in the eye [27,32,34,37]. The nature of these lesions indicate that aminoacetonitrile and related compounds may be a relative poison for mesodermally derived structures [32].

Attempts to define the biochemical influences which these compounds may exert upon the metabolic pathways functioning in epiphyseal cartilage have led to the observation that epiphyseal plates from experimental animals treated with these compounds have a reduced content of hexosamine, more specifically galactosamine, and also have reduced ability to synthesize hexosamine from glutamine and glucose-6-phosphate [7,8,26]. These investigations were carried out on pooled samples of epiphyseal cartilage, and could not be related to the specific areas where morphological alteration had occurred.

The recent adaptation of quantitative microchemical methods to the biochemical analysis of localized areas in the epiphyseal plate makes possible investigation of certain enzymic alterations which accompany these lesions and which may relate in causal manner to their production [12]. In this work several litters of young rabbits were treated after the manner used by Castellani, Castellani-Bisi, and Frigerio with aminoacetonitrile and sacrificed after lathyritic lesions had appeared [7,8]. The areas of differentiating cartilage cells in the epiphyseal plate were then studied for their content of several enzymes important to carbohydrate metabolism, and these results related to phosphorus content.

METHODS AND MATERIALS

Thirty-two white New Zealand rabbits from four litters were obtained three to four days following birth. Fourteen of these animals were placed in a control group, and the remaining eighteen animals were treated with aminoacetonitrile. Aminoacetonitrile (melting point, 146 degrees centigrade with decomposition) obtained as the dihydrogen salt †, was neutralized with sodium bicarbonate, and

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† Courtesy of Dr. I. V. Ponseti.

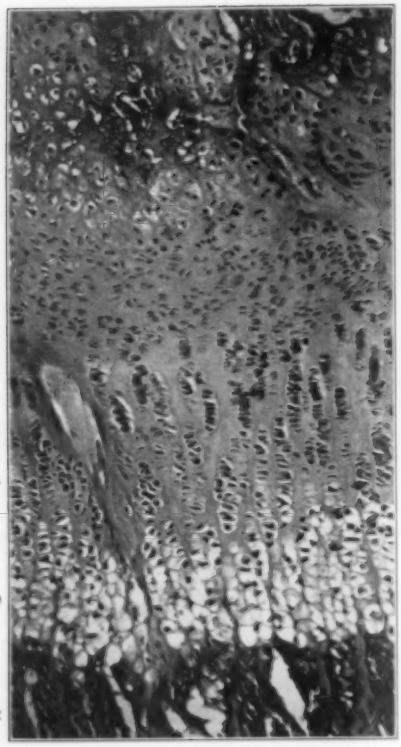

FIG. 1

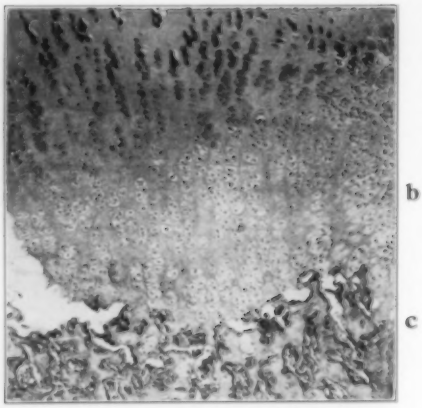

FIG. 2

Fig. 1: Cross section through the distal femoral epiphyseal plate of a normal ten-day old rabbit (97 ×). Tissue samplings are taken as indicated from: *a*, proliferating cartilage cell; *b*, hypertrophic cartilage cell; and *c*, primary spongiosa areas.

Fig. 2: Epiphyseal plate from a ten-day old rabbit which was treated with aminoacetonitrile (97 ×). Note the generalized disruption of the plate. Tissue samplings are taken as indicated from: *a*, disrupted proliferating cartilage cell; *b*, disrupted hypertrophic cartilage cell; and *c*, primary spongiosa areas.

ten milligrams were administered daily by subcutaneous injection to each animal of the experimental group [7,8,21]. The dose was reduced to seven milligrams per day in the case of one litter. A total of ten animals survived the aminoacetonitrile treatment (mortality rate, 55 per cent) and on the seventh to the eighth day the experimental and control animals were alternately sacrificed by cervical fracture. The animals were ten to fifteen days old at this time, and as nearly as possible the animals in both the experimental and control groups were of uniform size and age.

Immediately after sacrifice of each animal, the distal portion of the femora was excised, split longitudinally, mounted on filter paper for identification, and frozen in liquid nitrogen (−195 degrees centigrade). Blocks of frozen tissue were then prepared and mounted as described previously, and frozen sections twenty to twenty-five micra in thickness were cut at −10 to −15 degrees centigrade [17,19]. The frozen sections were then placed in special aluminum storage holders, and lyophilized in evacuated glass containers at −30 degrees centigrade, as described by Lowry [19]. Tissue sections so obtained were stored at −30 degrees centigrade *in vacuo* until ready for study. Tissues treated in this fashion preserve almost all their enzyme activity and organic constituents [19,20,21]. Specimens were also taken from the proximal tibial epiphysis for routine histological examination.

The lyophilized tissue preparations were then dissected free hand under a binocular dissecting microscope using magnifications of 10× to 25×. Tissue

samples were selected from the zone of proliferating cartilage cells, the area of hypertrophic cartilage cells, and the primary spongiosa, which also included the zone of provisional calcification [12,19] (Fig. 1). The morphology of the tissue obtained from the experimental animals was disrupted, but in each case representative samples were obtained from each of the areas (Fig. 2). No attempt was made to study the undifferentiated cartilage-cell areas in these experiments. From four to fifty tissue samplings were taken from each of the three areas in the epiphyseal plate selected for study. Analyses were made on the majority of the animals comprising the experimental and control groups, as specified in the tables. In most cases, five samples were taken from each location, and a total of 1,300 epiphyseal-plate samplings were analyzed.

The tissue samples obtained were approximately 0.06 square millimeter in area and 0.02 millimeter thick. The specimens were weighed to within 3 per cent accuracy on the Lowry quartz fiber balance and placed in special microtestubes [16,17,19]. The weight of these samples varied from 0.4 to 3×10^{-6} grams. The weighed tissue samples were then assayed for glucose-6-phosphate, malic and lactic dehydrogenase and phosphoglucoisomerase, alkaline phosphatase, and total phosphorus content. Previously described methods of assay were used in each case [8,12,13,20,21,22,23,24]. The results of the enzyme assays are reported in terms of moles of substrate oxidized or converted per kilogram of total dry tissue per hour, and the phosphorus content is reported in terms of moles per kilogram of total dry weight of tissue.

RESULTS

Aminoacetonitrile Lesions

The animals which were treated with aminoacetonitrile were weaker than those in the control group, and in several cases demonstrated lower-extremity paralysis and lack of coordination in walking. When dissected, the skin of the experimental animals was fragile and appeared to have poor tensile strength. Bone from the experimental animals was soft when cut and appeared osteoporotic.

Microscopically, the lesions which have been previously described as characteristic of lathyrism were observed (Figs. 1 and 2) [10,30,32,33,37]. The normally ordered arrangement of cartilage-cell columns in the epiphyseal plate was disrupted, with the disorganization most prominent in the hypertrophic cartilage-cell area. Hypertrophied cartilage cells were seen clumped together, and calcification occurred irregularly across the plate. Some variation in the severity of the lesions resulting from treatment was noted, but nevertheless, all the experimental animals were included in the experimental group for quantitative microchemical study.

Comparison of Normal Biochemical Anatomy of the Epiphyseal Plate of the Rabbit with that of the Dog.

The enzyme and phosphorus distribution throughout the epiphyseal plate of the normal young rabbit is much the same as that which has been reported to exist in the plate of the young dog (Tables I, II, and III; Figs. 3, 4, and 5) [12]. The epiphyseal plate of the rabbit is generally more active enzymatically than that of the dog, as can be seen by comparison with previously published data [12].

Lactic Dehydrogenase and Phosphoglucoisomerase

The distribution of these two enzymes in the epiphyseal plate is similar in the rabbit and the dog (Table I, Figs. 3 and 4). Lactic dehydrogenase has its

TABLE I

ENZYME ACTIVITY IN EPIPHYSEAL-PLATE AREAS OF THE NORMAL RABBIT *

Location	Lactic Dehydrogenase	Malic Dehydrogenase	Glucose-6-Phosphate Dehydrogenase	Phosphoglucoisomerase	Alkaline Phosphatase
Primary spongiosa	12.5 ± 1.82 n = 7 dtm = 40	8.23 ± 1.49 n = 6 dtm = 25	0.400 ± 0.063 n = 8 dtm = 28	15.9 ± 3.64 n = 7 dtm = 33	13.6 ± 2.26 n = 6 dtm = 26
Hypertrophic cartilage-cell area	51.4 ± 3.91 n =7 dtm = 40	7.87 ± 0.512 n = 6 dtm = 20	0.219 ± 0.032 n = 8 dtm = 30	26.7 ± 3.81 n = 7 dtm = 28	12.3 ± 2.84 n = 6 dtm = 20
Proliferating cartilage-cell area	59.6 ± 5.22 n = 7 dtm = 44	6.45 ± 0.832 n = 6 dtm = 24	0.197 ± 0.032 n = 8 dtm = 34	41.7 ± 4.04 n = 7 dtm = 31	1.89 ± 1.14 n = 6 dtm = 33

* All activity is expressed as moles of substrate converted or oxidized per kilogram total dry weight of tissue per hour ± the standard error of the mean; n refers to the number of animals studied in each case; and dtm refers to the total number of analyses done on the animal group studied.

TABLE II

ENZYME ACTIVITY IN EPIPHYSEAL-PLATE AREAS OF RABBITS WITH LATHYRITIC LESIONS *

Location	Lactic Dehydrogenase	Malic Dehydrogenase	Glucose-6-Phosphate Dehydrogenase	Phosphoglucoisomerase	Alkaline Phosphatase
Disrupted primary spongiosa	10.5 ± 1.09 n = 9 dtm = 56	9.26 ± 0.74 n = 7 dtm = 27	0.247 ± 0.038 n = 9 dtm = 39	8.15 ± 1.74 n = 7 dtm = 36	12.4 ± 1.43 n = 7 dtm = 29
Disrupted hypertrophic cartilage-cell area	34.3 ± 2.09 n = 9 dtm = 59	7.14 ± 1.03 n = 7 dtm = 29	0.148 ± 0.018 n = 9 dtm = 31	19.1 ± 2.94 n = 8 dtm = 39	11.6 ± 1.41 n = 8 dtm = 54
Disrupted proliferating cartilage-cell area	44.9 ± 4.78 n = 9 dtm = 46	8.04 ± 0.618 n = 7 dtm = 24	0.194 ± 0.021 n = 9 dtm = 29	27.2 ± 4.80 n = 8 dtm = 42	0.047 ± 0.322 n = 7 dtm = 35

* All enzyme activity is expressed as moles of substrate converted or oxidized per kilogram total dry weight of tissue per hour ± the standard error of the mean; n refers to the number of animals studied in each case; and dtm to the total number of analyses done on the animal group studied.

TABLE III

PHOSPHORUS CONTENT OF NORMAL AND LATHYRITIC RABBIT EPIPHYSEAL PLATES *

Location	Total Phosphorus Content (moles/kilogram dry weight of tissue)	
	Normal	Aminonitrile Treated
Primary spongiosa	2.70 ± 0.15 n = 6 dtm = 24	2.79 ± 0.15 n = 6 dtm = 24
Hypertrophic cartilage cells	0.763 ± 0.64 n = 6 dtm = 23	1.04 ± 0.17 n = 5 dtm = 21
Proliferating cartilage cells	0.076 ± 0.073 n = 7 dtm = 37	0.084 ± 0.039 n = 7 dtm = 31

* Data is expressed as moles per kilogram total dry weight ± the standard error of the mean; n represents the number of animals in each case; and dtm the total number of analyses performed on the animal group studied.

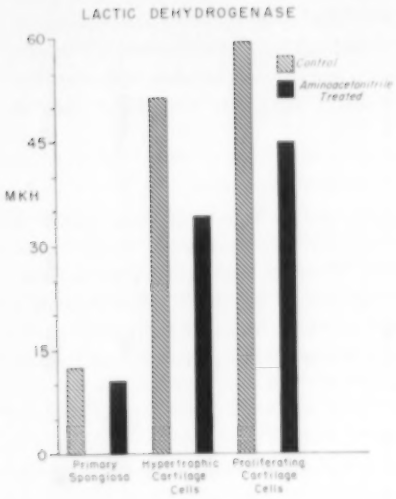

FIG. 3

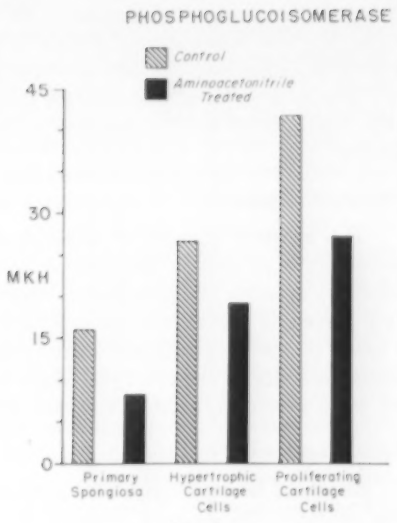

FIG. 4

Fig. 3: Lactic dehydrogenase in the specified epiphyseal-plate areas obtained from normal and lathyritic rabbits. Activity is expressed as moles of substrate converted per kilogram total dry weight per hour.

Fig. 4: Phosphoglucoisomerase activity in the specified areas of the epiphyseal plate obtained from normal and lathyritic animals (Fig. 3).

Fig. 5: Glucose-6-phosphate dehydrogenase activity in the specific areas of the epiphyseal plate obtained from normal and lathyritic animals (Fig. 3).

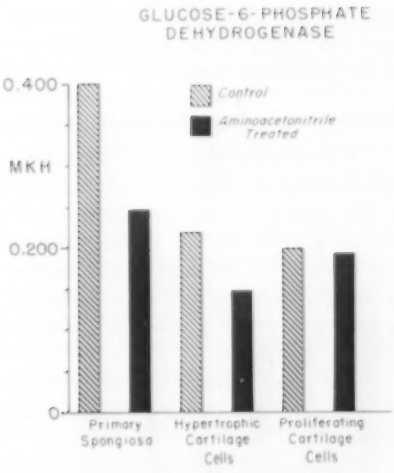

FIG. 5

peak activity in the proliferating-cell area, falls slightly in the hypertrophic cartilage-cell area, and then drops precipitously in the zone of provisional calcification and primary spongiosa. Phosphoglucoisomerase follows this same pattern of distribution, but undergoes a somewhat more gradual transition as the cartilage cells mature.

Malic Dehydrogenase

Of the enzymes studied in the epiphyseal plate, this is the only one which was less active in the rabbit than in the young puppy. As in the dog, this enzyme was most active in the primary spongiosa and zone of provisional calcification; its activity in the other two locations studied was nearly equal.

Glucose-6-Phosphate Dehydrogenase

In the epiphyseal plate of the young rabbit the characteristic distribution of

glucose-6-phosphate dehydrogenase, previously reported in the epiphyseal plate of the dog [12], is demonstrated (Table I, Fig. 5). The enzyme has a constant level of activity as the cartilage cells traverse the proliferating and hypertrophic stages, but then its activity almost doubles as bone is formed and vascular invasion occurs. The over-all level of activity is considerably higher in the rabbit than in the dog.

Alkaline Phosphatase

The greatest amount of alkaline phosphatase in the epiphyseal plate of the rabbit is present in the area of newly formed bone; however, there is less difference between the phosphatase content in this area and in the one immediately preceding it than was the case in the epiphysis of the dog [12]. When account is taken of the enzymatically inert bone salt in these areas, the alkaline phosphatase activity in the epiphysis of the rabbit is considerably higher than that in any other previously studied location or tissue [12,25].

Total Phosphorus

As would be expected from its content of bone salt, the primary spongiosa area contains the greatest amount of phosphorus (Table III). Considered in terms of phosphate, 25 per cent of the tissue weight in the primary spongiosa area, 7.3 per cent of the weight of the hypertrophic cartilage-cell area, and less than 1 per cent of the weight of the proliferating cartilage-cell area are the result of the phosphate content.

Biochemical Lesions Resulting from Aminoacetonitrile Administration

The enzyme content of all three areas in the epiphyseal cartilage from the experimental animals was significantly different from that in the control animals in the case of lactic dehydrogenase, glucose-6-phosphate dehydrogenase, and phosphogluciosomerase. In the experimental group, lactic dehydrogenase activity was reduced 33 per cent in the hypertrophic cartilage-cell area and 25 per cent in the proliferating cell area (Table II, Fig. 3). A slight lowering of lactic dehydrogenase activity was also present in the zone of provisional calcification and primary spongiosa.

The most marked loss of activity, however, occurred in the hypertrophic-cell area, where damage resulting from aminoacetonitrile administration is most marked.

Glucose-6-phosphate dehydrogenase activity in the experimental group was reduced 38 per cent in the zone of provisional calcification and primary spongiosa, and 32 per cent in the hypertrophic cartilage-cell area. The proliferating cartilage-cell area was unaffected by aminoacetonitrile administration.

Phosphoglucoisomerase activity was generally reduced in all three areas studied (Table II, Fig. 4). After aminoacetonitrile treatment, malic dehydrogenase activity underwent minor fluctuations of questionable significance in the hypertrophic-cell area and primary spongiosa (Table II). Malic dehydrogenase activity increased 25 per cent in the proliferating cartilage-cell area. Alkaline phosphatase was particularly unaffected by aminoacetonitrile treatment in either the primary spongiosa or hypertrophic cartilage-cell area (Table II). Its activity was, however, reduced in the proliferating cartilage-cell area. Aminoacetonitrile treatment does not affect the total phosphorus content in the primary spongiosa area, but does slightly increase it in the hypertrophic-cell area, where, considered as phosphate, it represents 9.9 per cent of the area's total dry weight (Table III).

DISCUSSION

This work demonstrates changes in enzyme activity and phosphorus content in certain regions of the epiphyseal plate of animals treated with aminoacetonitrile. There is little quantitative data available on the effects of nutrition, disuse atrophy, or paralysis on the tissue chemistry of bone or cartilage. However, data indicating the effects of vitamin and protein deficiency and fructose administration upon the content of several enzymes and co-enzymes in liver have been presented [4,6,9]. From these observations, some general idea of the response of tissue enzymes to nutritional alterations may be obtained. Burch has carried out extensive studies of the enzyme modifications accompanying malnutrition. In her study of liver-biopsy specimens from thirteen children with kwashiorkor, a disease of severe protein malnutrition, she observed reduction of xanthine oxidase, D-amino acid oxidase, glycolic acid oxidase, reduced diphosphopyridine nucleotide dehydrogenase, and malic dehydrogenase [4]. When rats are subjected to a riboflavin-deficient diet with normal protein levels, no reduction in liver protein is observed, but xanthine oxidase, D-amino acid oxidase, and glycolic acid oxidase all fall in activity soon after the diets are begun. Reduced diphosphopyridine nucleotide dehydrogenase is remarkable in that its activity remains stable [5]. In scurvy, Banerjee and his associates reported reductions of lactic, malic, and succinic dehydrogenase activity with no change in tissue pyridine nucleotide content [2]. At the other extreme, Fitch and his associates demonstrated a ten-fold enhancement of liver glucose-6-phosphate dehydrogenase content in animals fed diets rich with fructose [9].

These observations demonstrate that the tissue enzyme content of an animal is related to its general nutritional state. Certain enzymes, however, are much more easily disturbed by dietary deficiency than others. Those enzyme systems particularly susceptible to modification by vitamin deficiency are the labile ones requiring as a part of their molecule a B-vitamin co-enzyme. In particular, these are xanthine oxidase, D-amino acid oxidase, and glycolic acid oxidase which require flavinadenine dinucleotide and flavin mononucleotide [4,5]. Lactic and malic dehydrogenase are less influenced in deficiency states and require diphosphopyridine nucleotide [4,5]. Glucose-6-phosphate and 6-phosphogluconic dehydrogenase are markedly affected by dietary variations as pointed out previously [9].

It is not surprising, then, that the biochemical alterations produced in the epiphyseal plate by aminoacetonitrile administration are not limited to one system but rather are characterized by widespread reduction in activity of several enzyme systems. In addition to those enzyme systems which have been shown in this work to be influenced by aminoacetonitrile administration, Pedrini and Pedrini-Mille have pointed out previously that there is also reduction of hexosamine synthetase activity in lathyritic cartilage [26]. In interpreting the results of the present study, one must consider the general nutritional state of the experimental and control animals. Administration of aminoacetonitrile caused observable systemic effects and part of the biochemical lesion which was observed might reflect only a state of malnutrition. I do not believe this was the case since the food intake of the experimental animals was identical to that of the control animals except that it was less in total amount. The aminoacetonitrile treatment was continued for only seven to eight days, after which the animals were sacrificed. Since the parent animal and the litter were in good nutritional state at the onset of the experiment, it would be difficult or impossible to induce changes due simply to nutritional deficiency this rapidly unless the aminoacetonitrile acted as a competitive inhibitor for some essential factor or vitamin. In the latter case, the results could then not be considered strictly due to malnutrition. A period longer than one week is generally required to produce nutritional deficiency in animals.

Lower-extremity paralysis is a frequent accompaniment of aminoacetonitrile treatment [27]. The effects of paralysis and immobilization upon epiphysis and bone chemistry are largely unknown, except that with prolonged immobilization osteoporosis and lowered phosphatase activity occur. Gradual, incomplete paralysis developing over a seven-day period would not be expected to produce appreciable secondary biochemical modifications in the epiphyseal cartilage.

The direct quantitative relationship between enzyme activity and the over-all function of the pathway in which it participates is largely unknown. It would seem, however, that to some extent enzyme activity and function are related [11,14]. With reductions of lactic dehydrogenase, glucose-6-phosphate dehydrogenase, phosphoglucoisomerase, and hexosamine synthetase, a generalized deficiency of metabolic intermediates and high-energy phosphate bonds for the proper formation of tissue constituents might be expected to occur with resultant formation of defective structure during growth.

Attempts to explain the mechanism by which lathyritic lesions are induced must also take into account the striking protective effects exerted by thyroxine and triiodothyronine [28,29]. In this regard, Smith and Williams-Ashman have shown that thyroxine in large doses, comparable to those used by Ponseti, increase the activities of several enzymes, including hexokinase, succinic oxidase, and adenosine triphosphatase in skeletal tissues [35]. A similar observation also has been made by Tipton and Nixon [36]. These effects of thyroxine are in addition to its ability to uncouple oxidative phosphorylation [15]. These changes in tissue enzyme protein associated with thyroxine administration have been explained to be result of an intracellular shift of the protein-carrier moities of these enzymes [38]. It is possible that thyroxine and triiodothyronine prevent aminoacetonitrile lesions by producing a compensatory increase in some of the enzymes which, otherwise, would be reduced to levels low enough to compromise function.

In view of the osteoporotic nature of lathyritic bone, it is of particular interest that neither alkaline phosphatase activity nor total phosphorus content is influenced in the primary spongiosa area. Actually an increased phosphorus content in the hypertrophic cell area was observed, which may indicate an altered capacity for phosphorus binding by collagen fibrils. The calcification defect in the lathyritic plate could be related to either an interruption of the supply of phosphate ester derived from carbohydrate metabolism or to a disturbance in ground-substance formation. No clear-cut disturbance of mineral metabolism has as yet been demonstrated [30]. The normal total phosphorus content in the primary spongiosa area would indicate that the supply of phosphatase substrate is adequate. These observations suggest that there may be a defect in the formation of ground substance in which calcification normally occurs. Although the total collagen and basic amino acid content of lathyritic animal epiphyseal cartilage is not reduced, its content of hexosamine is [7,8]. In this regard, Follis and Tousimis have shown that lathyritic collagen has defective organization [10]. These alterations could be the result of a disruption of epiphyseal biochemistry such as has been described.

The generally higher levels of enzyme activity in the normal epiphyseal plate of the rabbit, as compared to the levels of that of the dog, are interesting and are probably related to the rabbit's more rapid growth rate. Alkaline phosphaase, phosphoglucoisomerase, and malic dehydrogenase were almost twice as active as they were in the dog epiphysis.

The biochemical alterations described here which accompany the generalized lesions resulting from aminoacetonitrile administration may not be identical to those accompanying administration of other lathyrogenic materials. These various other agents have demonstrated differences in affinity for specific tissues and some

variation in the amount that their action is suppressed by hormones [27,29,30].

The observation that multiple enzyme defects are present in aminoacetonitrile lathyrism is of interest in view of the striking morphological and physical similarities which have been previously pointed out between lathyrism and slipped epiphysis, Legg-Perthes disease, idiopathic scoliosis, and adolescent kyphosis [27].

The systemic effects of aminoacetonitrile administration involving many tissues suggest that enzymatic alterations similar to those present in the epiphyseal plate may be present in other tissues.

SUMMARY

Lathyritic lesions were induced in young growing rabbits by the administration of aminoacetonitrile. The animals with lathyritic lesions and those in a control group were sacrificed and frozen-dried sections were prepared from the epiphyseal plate of the femur after the method of Lowry. By use of specialized methods, the proliferating and hypertrophic cartilage-cell and primary-spongiosa areas of these animals were studied for their content of lactic, malic, and glucose-6-phosphate dehydrogenase, phosphoglucoisomerase, alkaline phosphate, and total phosphorus. Striking depression of lactic and glucose-6-phosphate dehydrogenase activity was observed in the areas of the hypertrophic cartilage cells and primary spongiosa. Phosphoglucoisomerase was reduced throughout all three areas. On the other hand, the content of total phosphorus, malic dehydrogenase, and alkaline phosphate in these areas was not disturbed. The most severe enzyme alterations occurred in those areas most disrupted by aminoacetonitrile.

From these and previous observations, it is felt that the morphological disruption of the epiphyseal plate associated with aminoacetonitrile treatment results from the reduction in activity of several enzyme systems normally providing metabolic intermediates and high-energy phosphate necessary for tissue synthesis. These observations are discussed in relation to the nutritional status of the animals, previous studies of the developing epiphyseal plate of the dog, and the protective effects of thyroxine and triiodothyronine against aminoacetonitrile lesions.

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Skeletal Changes in Suckling Rats Induced by Prolonged Papain Administration*†

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Thomas was the first to observe collapse of rabbit ears after the intravenous injection of papain [19]. Only crude papain can be utilized for *in vivo* studies if this enzyme is to reach its site of action [12,13,22]. After a single injection of crude papain, chondroitin sulphate is elevated in the blood and urine [1,21]. From this body of evidence it has been suggested that the loss of mucopolysaccharide from epiphyseal plates is due to the cleaving by papain of chondroitin sulphate from

TABLE I

GROSS AND MICROSCOPIC OBSERVATIONS IN BOTH CONTROL AND TEST ANIMALS

					Gross		Microscopic			
					Shortening of Humerus or Femur		Dyschondroplasia of Epiphyseal Plate		Nucleus Pulposus	
Series	Duration (*Days*)	Intraperitoneal Injection	Sex	Average Weight at Autopsy (*Grams*)	(*Altered*)	(*Total*)	(*Altered*)	(*Total*)	(*Altered*)	(*Total*)
1	23	Saline	F	96	0	1	0	1	2	11
2	23	Papain	M and F	73	5	5	5	5	46	50
3	49–53	Saline	M	234	0	8	0	8	14	52
4	49–53	Saline	F	173	0	16	0	13	22	82
5	49–53	Papain	M	169	9	9	7	8	34	36
6	49–53	Papain	F	133	9	9	4	9	45	46
7	54–69	Saline	M	260	0	14	0	13	13	57
8	54–69	Saline	F	202	0	7	0	7	5	37
9	54–69	Papain	M	171	10	17	7	17	84	90
10	54–69	Papain	F	149	13	14	5	13	87	96
				Control: 0/46			0/42		56/239 (23.4 per cent)	
				Test: 46/54			28/52		296/318 (93.0 per cent)	

cartilaginous protein [16,17,20]. Many experiments to investigate the enzyme action of papain on cartilage after one injection have been undertaken. Observations have also been made on the effect of repeated daily injections of papain continued for as long as fourteen days in young rabbits, mice, rats, guinea pigs, cats, and dogs [2,6,7,8,9]. Shortening of bones secondary to closure of epiphyseal plates occurs readily in rabbits and mice, whereas rats are more resistant [8]. To our knowledge, there are no documented examples of gross skeletal deformities produced by papain in rats. For this reason it seemed desirable to determine the effect of long-term, repeated papain injections on skeletal development in young rats. Under these circumstances, irreversible alterations were observed in epiphyseal plates, long bones, and intervertebral discs of test animals. In addition, an extensive generalized derangement occurred in endochondral-bone formation.

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† Results presented at the Annual Meeting of the Federation of American Societies for Experimental Biology, Chicago, Illinois, April 14, 1960.

MATERIALS AND METHODS

Sixteen pregnant Sprague-Dawley female rats weighing 150 to 250 grams were used in this study. After breeding, each animal was transferred from regular wire-mesh mating cages to individual metal family units containing a floor tray lined with shavings. Purina rat-chow diet and water were supplied *ad libitum* during the gestation (twenty-two days) and nursing periods. A 1 per cent crude papain suspension was prepared, buffered to pH 7 with 3.6 per cent NaOH, and maintained under constant refrigeration. This suspension was agitated vigorously before the daily intraperitoneal injection of 0.2 cubic centimeter was administered to fifty-four ten-day-old suckling rats for periods of twenty-three to sixty-nine days (Table I). Equivalent volumes of normal saline solution were injected into forty-six control litter mates for similar periods. The young rats were weaned at three weeks and placed on a pellet diet for the remainder of the experiment. At autopsy, tissue was removed from both visceral and skeletal organ

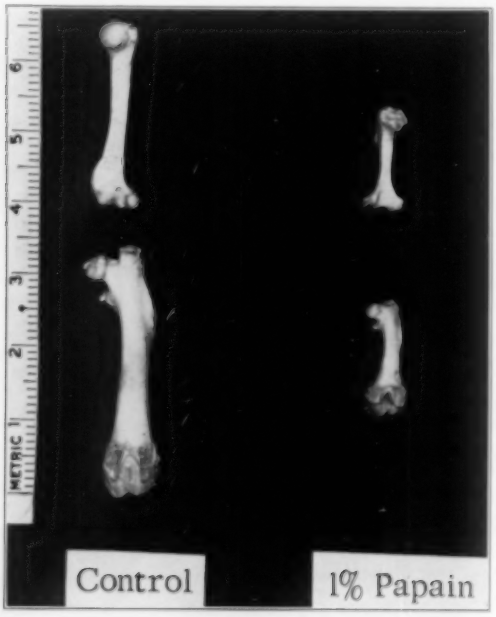

FIG. 1

Humeri and femora from a control rat and a litter mate which received a daily injection of 1 per cent suspension of papain for sixty-nine days. Marked reduction in the length of the long bones and widening of the distal end of the humerus are apparent.

systems. Abnormalities of animal growth and shape were noted and recorded. Vertebral columns were severed between the upper cervical and lower thoracolumbar vertebrae, cleaned of rib and muscle attachments, and decalcified, along with a humerus and femur, in 1N HCl for twenty-four hours. Both control and test vertebral bodies were sectioned in a mid-sagittal plane, with retention of the spinal cord and spinous processes for consistent orientation on histological examination.

All tissues were then returned to the fixative and later were embedded in paraffin, sectioned at six micra, and stained with hematoxylin and eosin.

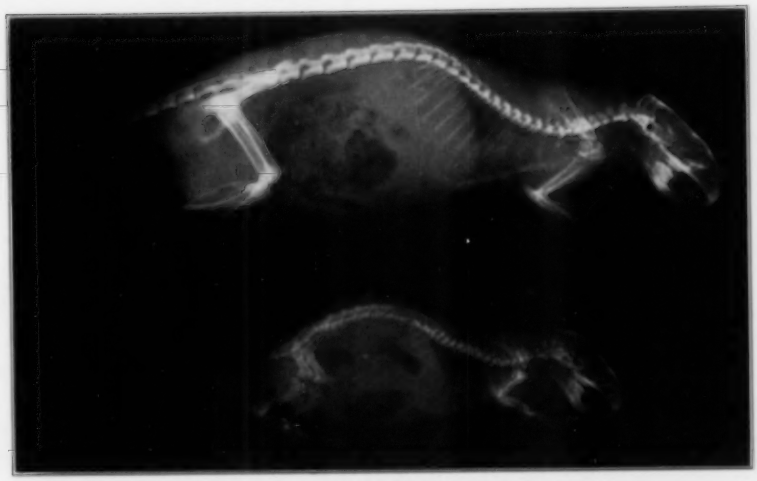

FIG. 2

Roentgenogram of a control rat and a litter mate which received a daily injection of 1 per cent suspension of papain for sixty-one days. Retardation of growth, splayed-out ends of the long bones (tibiae and femora), and a suggestion of lordosis of the thoracic spine are evident in the test rat.

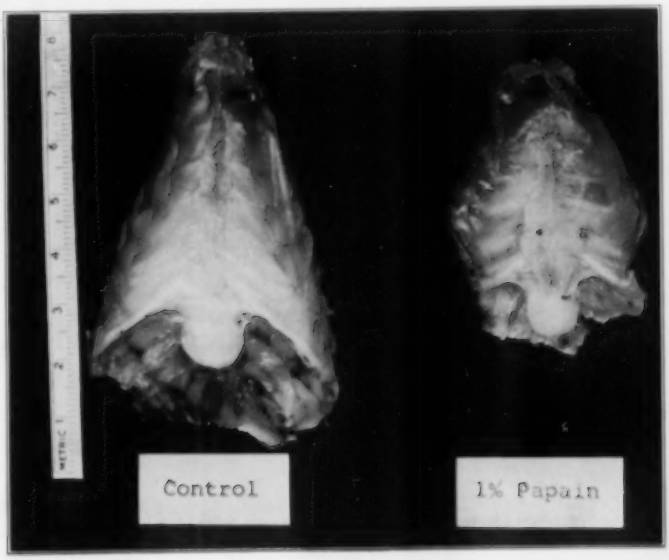

FIG. 3

Anterior view of thoracic cages from a control rat and a litter mate after daily injection of papain for sixty-one days. The test thorax is diminished in size, its shape is altered, and the caudad ribs are deformed.

RESULTS

Twenty-four hours after the first papain injection, swollen, red joints in all extremities and deep sternal concavities developed in the suckling rats. Within the ensuing twenty-four hours, these alterations subsided except for an occasional persistent sternal deformity. Several days later it was noted that the test animals

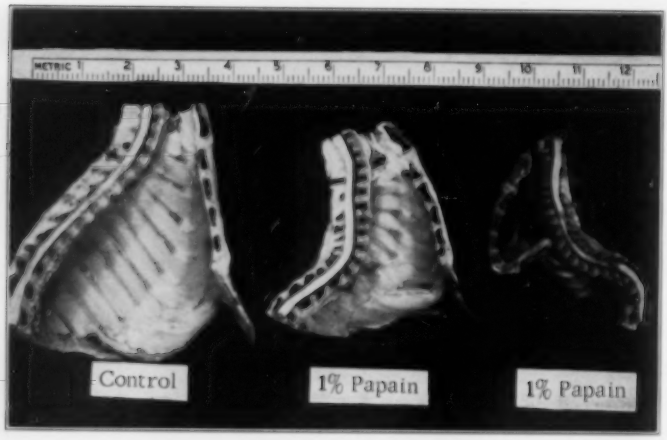

FIG 4

Hemisection of thoracic cages from one saline-injected control and two test rats which received intraperitoneal injections of papain for sixty-one days are shown. Note the lordosis and deformities of the ribs and sternum in the test specimens.

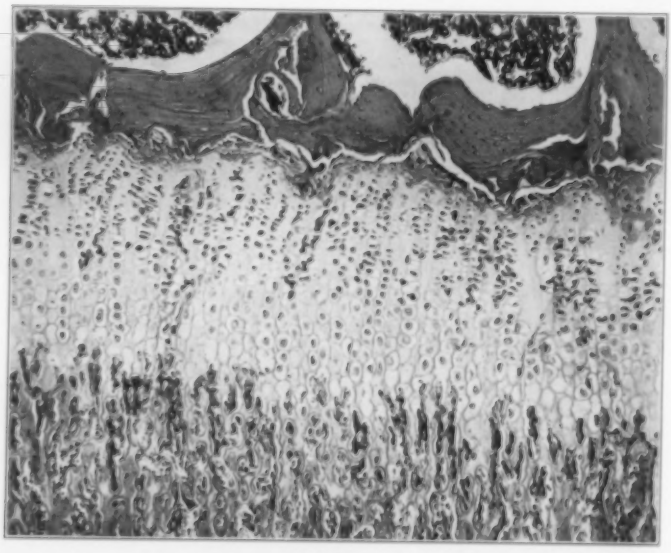

FIG. 5

Epiphyseal plate of a control femur composed of longitudinal parallel rows of cartilage cells and continuous adjacent endochondral bone (hematoxylin and eosin, × 150).

were not growing as rapidly as the controls. By the tenth day, there were palpable deformities of the thoracic cage. Several days after the initial injection, it was noted that test animals frequently bled for short periods of time after a papain injection, whereas the controls did not manifest this bleeding tendency. Repeated daily papain injections for periods of twenty-three to sixty-nine days exerted a depressing effect on both weight gain and endochondral-bone growth. Consistent weight differences between control and test animals of the same sex were directly proportional to the duration of the experiment (Table I). To gross inspection the lengths of the femora and humeri in the test animals were reduced to one-third

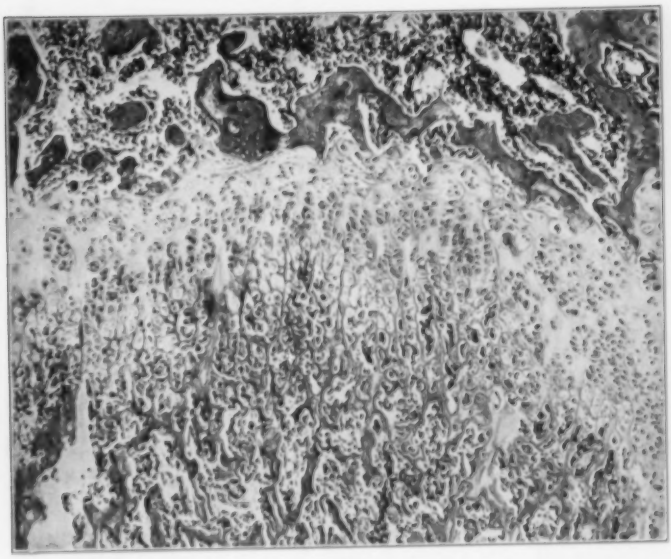

FIG. 6

Epiphyseal plate of a papain-injected animal, composed of irregular non-parallel groups of small chondrocytes. Note the reduction in the thickness of the plate and the irregular, discontinuous, adjacent endochondral bone (hematoxylin and eosin, × 150).

to one-half of the lengths of the same bone of the control litter mates in forty-six of fifty-four test animals (Fig. 1). Roentgenograms of long bones indicated increased splaying of the distal ends and closure of the epiphyseal plates (Fig. 2). A relative excess of histologically normal striated muscle surrounded these shortened long bones. The normal pyramidal contour of the thorax was shorter and more elliptical (Fig. 3). The caudad ribs were distorted in regions adjacent to and including the costochondral junctions (Fig. 4). A thoracolumbar lordosis was observed in one-half of the test vertebral columns. Complete or partial loss of flexibility of the vertebral column was encountered in most of the test rats.

Microscopic examination of the epiphyseal plates of the femora and humeri revealed the following alterations in twenty-eight of fifty-two test animals: the chondrocytes were not aligned in parallel longitudinal columns, the thickness of the epiphyseal plate was reduced by from one-third to two-thirds in breadth, and the bone spicules were intensely stained and thickened (Figs. 5 and 6). Newly formed endochondral bone adjacent to the zone of resting cartilage cells was disrupted (Figs. 5 and 6).

Histological preparations of the intervertebral discs revealed striking changes. In most of the control discs there was a central myxomatous nucleus pulposus surrounded by compressed chondrocytes, peripheral fibrocartilage (annulus fibrosus), and the adjacent ossification centers (Fig. 7). In contrast to this picture, 296 of the 318 test discs showed swelling of the chondrocytes, eosinophilic degeneration, necrosis of the nucleus pulposus, partial to complete replacement of the nucleus pulposus by hyaline cartilage and collagen, and disorganization of the ossification centers identical to that observed in the epiphyseal plates of the long bones (Fig. 8). The effect of these changes was, first, to shorten the test vertebrae so that they had a cubical rather than their normal rectangular contour, a change noted by Hulth [6,7], and second, to produce loss of flexibility of the spine. Some of these changes were noted in the control discs. In the forty-two control vertebral

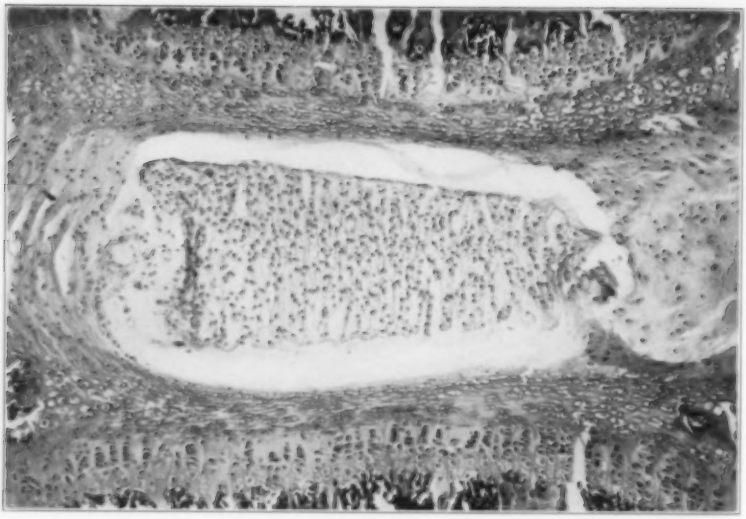

FIG. 7

A control thoracic intervertebral disc consisting of the central nucleus pulposus and a surrounding annulus fibrosus. The chondrocytes adjacent to the nucleus pulposus are compressed and the structure of the epiphyseal plates is similar in arrangement to Fig. 5 (hematoxylin and eosin, × 150).

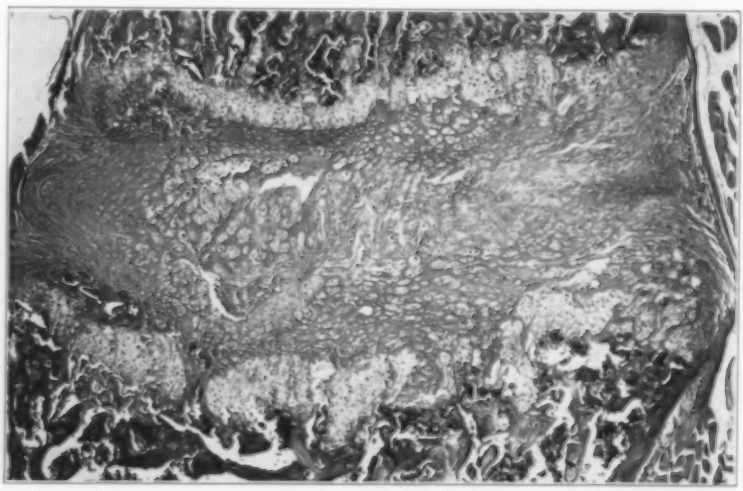

FIG. 8

A test thoracic intervertebral disc showing complete replacement of the nucleus pulposus by hyaline cartilage and collagen. In addition, the chondrocytes are swollen and the epiphyseal plates are disrupted, as in Fig. 6. Because of thickening of the intervertebral discs it was necessary to reduce the magnification two-thirds to obtain a photomicrograph comparable to Fig. 7 (hematoxylin and eosin, × 50).

columns from litter mates of the test animals, 23 per cent of the discs, most frequently those in the lower thoracic and lumbar regions, showed replacement of the nucleus pulposus by cartilage and collagen but not the other changes in the adjacent chondrocytes and centers of ossification. In contrast to this, 93 per cent

of the discs in the fifty-two test vertebral columns manifested all of the disc alterations described (Table I).

DISCUSSION

Administration of papain injections for several weeks by Hulth and his associates produced premature closure of epiphyseal plates with retardation of longitudinal growth, especially in the long bones and a depression in weight gain [2,6,7,8,9]. We have confirmed these findings and, in addition, produced rigidity of the vertebral column and malformation of the thorax. Hulth also reported a symmetrical generalized retardation in growth of all tissues in rabbits receiving papain [7]. We observed a suppression of skeletal development and growth in rats. Muscle development was not inhibited as much so that a disproportion between bone and muscle was apparent.

Papain injections have a relatively profound effect on young rat cartilage. The gross skeletal deformities that became manifest within ten days of the onset of treatment persisted even when the daily injections were discontinued thereafter. Under identical circumstances, little or no effect was produced by papain on the skeleton of adult rats or rabbits [2,7,19]. Undoubtedly, this is due to increased resistance to the action of the enzyme or to a decrease in the cartilage-bone activity in adult rats with cessation of skeletal growth after the age of 120 days. In the rat, complete closure of the proximal tibial and distal femoral epiphyses does not occur until senescence (1,135 days) [15].

The rats with permanent changes caused by prolonged papain administration showed characteristics similar to those seen in dogs with familial achondroplasia characterized by shortened long bones with splayed-out ends and sternal deformities [4].

The gross rigidity of the vertebral column observed at autopsy of these rats was caused by changes in the fibrous and cartilaginous elements of the intervertebral discs. These changes bear some resemblance to the two types of disc degeneration described by Hansen as occurring spontaneously in animals [5].

It is also of some interest that Sylvén and his associates observed that the degenerative changes in the nucleus pulposus that occur with aging are characterized by loss of mucoid material and the simultaneous differentiation of collagen fibrils [18].

Although muscle necrosis and disturbance in blood coagulation have been observed after the intravenous administration of papain and other enzymes [10,11,14], the rats in these experiments exhibited no more than slight blood loss from the site of injection, suggesting some alteration in the clotting mechanism. There was no histological evidence of muscle necrosis. It would appear that the route of administration and the dosage play some role in producing muscle necrosis and hemorrhage. Microscopic examination of heart, lungs, intestinal tract, liver, kidneys, pancreas, spleen, and gonads from the test rats did not reveal any consistent or significant abnormalities.

SUMMARY

A crude papain suspension when injected intraperitoneally into suckling rats for twenty-three to sixty-nine days produced malformation of the sternum, rib cage, vertebral column, and caudad ribs. Permanent cartilaginous disorganization and epiphyseal-plate closure resulted in shortened long bones and vertebral bodies. Rigidity of the vertebral column was produced by degeneration of the nucleus pulposus, characterized by precipitation of eosinophilic necrotic debris and final replacement by hyaline fibrocartilage.

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Tissue Reactions to Metals—The Influence of Surface Finish*

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In attempting to remove a metal appliance inserted into bone for fracture fixation, surgeons have occasionally found one or more screws so firmly embedded that it was impossible to unscrew them. On such an occasion, the screwhead is sometimes twisted off, or the screw is removed by making a trephine hole around the screw or by chiseling away a variable amount of bone about the screw. The general experience has been that screws made of cobalt-chromium alloys are more often embedded in this way than stainless-steel screws, and accordingly, the belief has arisen, undocumented by other evidence, that there is a different reaction by the tissues to the two alloys. Since the surface finish of the cobalt-chromium screws used clinically is dull (vapor blasted) and therefore rougher than that of stainless-steel screws (electropolished), the difference in surface finish may be the critical factor rather than the composition of metal.

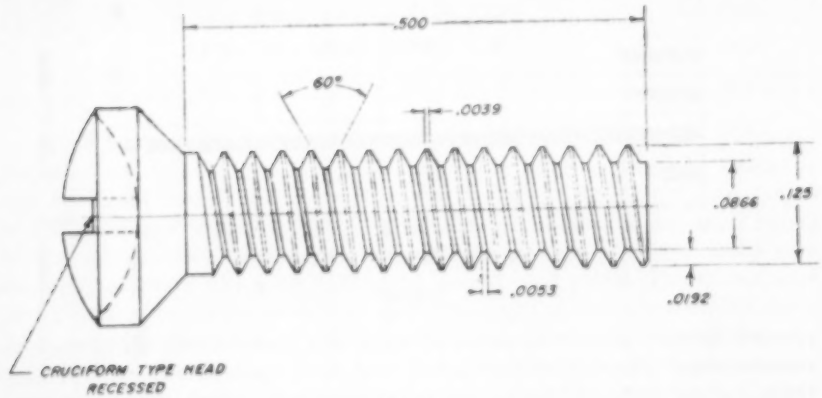

FIG. 1

Diagram of dimensions of screws used in the experiments.

The present study was planned to determine, if possible, what role the surface finish of the metal plays in the reaction of bone to screws, as determined histologically, and by measurement of the torque needed to unscrew them. The experiment was done in two sections. The *in vivo* part consisted in the insertion into dogs' bones of screws of identical material, size, and shape but having three different finishes. After convenient intervals, the screws were removed by use of a torque-wrench-screwdriver which allowed measurement of the firmness of set. Histological examination of the bone surrounding the screw holes was then done. In the *in vitro* part, the screws were inserted into several materials and the removal torques

* This research was aided by a grant from the National Institutes of Health, the United States Public Health Service—RG-4251.

were then recorded. A setup was finally devised which paralleled the *in vivo* results and bore a close resemblance to the clinical problem.

MATERIALS AND METHODS

A number of screws of cobalt-chromium alloy were specially prepared. Screw blanks were cast and the screw threads were then precision ground and cleaned before surface finishes were applied. The dimensional specifications are given in Figure 1. The dimensional variations are shown in Chart I. The measurements

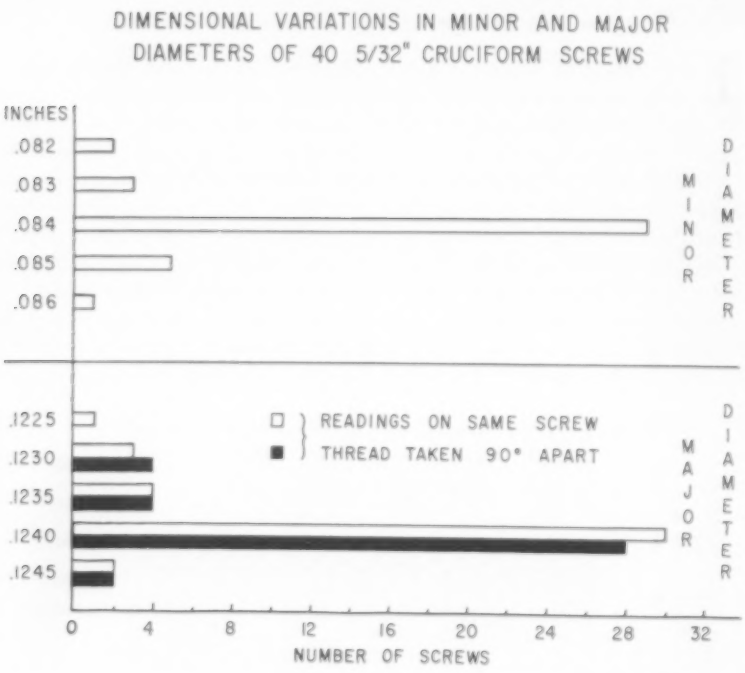

CHART I

of outer diameter of cross sections were made with a micrometer, whilst the inner cross-sectional diameter was measured with a comparator. The sand-blasted finish was the result of blasting with sixty-mesh sand. The vapor-blasted finish was applied over the sand-blasted finish. The electropolished finish was effected on the original ground surface by electropolishing at 130 degrees Fahrenheit for one minute in an electrolytic polishing solution. The thickness of the surface finish, measured with a profilometer with fine stylus, was, for the sand-blasted finish, thirty to thirty-five micro-inches, for the vapor-blasted finish, forty to fifty micro-inches, and for the electropolished finish, twenty to twenty-five micro-inches.

The torque-wrench-screwdrivers consisted of ordinary commercial torque wrenches with Phillips screwdriver attachments (Fig. 2). Three different wrenches were needed to measure different ranges of torque expressed in inch-pounds. The wrenches designed for -5 to $+5$ and for -10 to $+10$ inch-pounds had $\frac{1}{2}$ inch-pound markings and were readable to better than $\frac{1}{4}$ inch-pound and to $\frac{1}{4}$ inch-pound, respectively, the values being reproducible to $\frac{1}{4}$ inch-pound. The wrench designed for -24 to $+24$ inch-pounds had gradations of one inch-

pound and was readable to ½ inch-pound, the values being reproducible on *in vitro* tests to ½ inch-pound. Care had to be taken that the cruciate head of the screwdriver was firmly in the cruciform slot before torque was initiated. A slow and gradual application of counterclockwise torque resulted in sudden release of the screw, at which moment the measurement of torque was recorded by means of a small magnet pushed along the scale by the indicator. The torque for removal was thereafter nearly always somewhat less than the initiating torque, and it varied appreciably when the speed of turning was inconstant but was relatively stable at a slow constant turning speed. After removal, each screw was placed in a labeled box for subsequent examination.

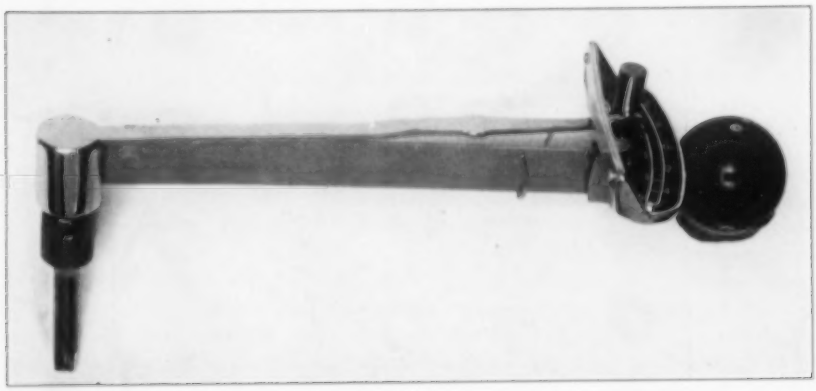

FIG. 2

Photograph of torque wrench used in experiments. The spring is held open by part of a paper clip to show its actions. The position of the cylindrical magnet indicates two inch-pounds of torque.

The object of the *in vitro* experiments was to devise a setup in which the recipient medium would so grip the screw after insertion that the torque of removal would exceed that of insertion and in which a difference in the torque of removal would be demonstrable for the different finishes. First, wood blocks of pine, ash, and rock maple were used; acrylic plastic was also tried. Holes were drilled by machine drill using 3/32 and 5/64-inch drill points. The screws were slowly inserted by torque screwdriver, and the torque of insertion recorded. Since the torque of insertion did not differ from the torque of removal by more than one inch-pound in any of these tests, and since no detectable differences between screws of different surface finish occurred, a few modifications were tried. Wetting or steaming the wood blocks after insertion of the screws proved ineffective. Liquid type-metal was allowed to cool and set around specimens from the three groups of screws, and the torque for removal was determined. Cold-setting metal solder (lab-metal) was used similarly. By these tests, no constant difference could be shown in the torques of removal according to the different finishes of screw. The recorded results (Table I) were obtained when acrylic plastic, in the presetting stage, was packed into the 3/32-inch holes in the acrylic block just prior to the insertion of the screws, and the screws removed after the plastic had thoroughly set. Finally, similar results were obtained by pouring viscous epoxy resin glue into 5/64-inch holes in rock maple, just prior to the insertion of the screws (Figs. 3-A and 3-B). The screws were then removed the next day.

In the *in vivo* experiments, the screws were cleaned, following the routine of Laing, to ensure the removal of surface foreign material, and then they were weighed to the nearest 0.05 milligram before use.

Two mongrel dogs, which weighed 11.5 and ten kilograms respectively, were used. On each dog three operations were performed, separated by intervals of one month. Each operation consisted in the exposure of the tibia or ulna and the insertion therein of twelve or fifteen screws. At operation, with the use of a tourniquet and aseptic technique, the periosteum was raised over the mid-shaft of the length of the bone and 3/16-inch holes were hand-drilled through the medullary cavity and both thicknesses of cortex. The drill holes were separated sufficiently so that the screwheads would not superimpose. The line of screw holes

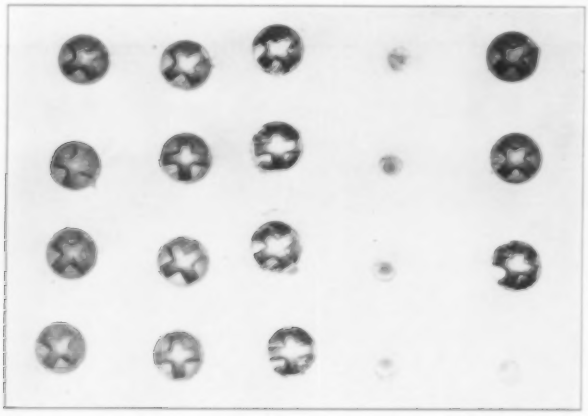

FIG. 3-A

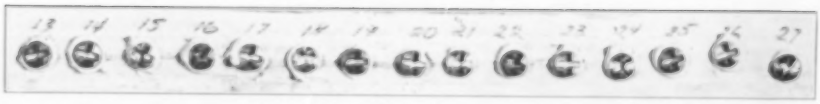

FIG. 3-B

One block each of the acrylic and epoxy glue experiments. The different finishes of screw can be seen.

followed the contour of the bone. In two operations only twelve holes were made, whereas in the other four there were fifteen holes. Into each hole a screw was inserted, usually by finger pressure. Screws with each of the three finishes were serially placed so that each bone received four or five screws of each surface finish. Occasionally, a screw would not pass easily into its hole by finger pressure, and the handle of the scalpel was used as a screwdriver for several turns, but even so, the loose fit finally allowed finger pressure to push the screwhead home. The wounds were closed in layers and the animals were sacrificed four months after the initial operations. Thus, specimens representing two months, three months, and four months of repair were obtained.

At sacrifice, the bones operated on were removed and placed fresh in a vise for removal of the screws, using the torque wrenches previously described. After removal and recording of the removal torques, each screw was placed in a labeled box for examination later, and the bone specimens were fixed in 10 per cent formalin. They were then decalcified and sections taken axially through the center of each screw hole. Embedding was in celloidin and staining was by hematoxylin and eosin and Prussian blue. The screws were examined by low-power microscopy after thorough removal of all adhering material. They were then weighed to the nearest 0.05 milligram and the weight compared with the original weight.

TABLE I*

	Acrylic	Epoxy Glue	*In Vivo* (2 mos.)	*In Vivo* (3 mos.)	*In Vivo* (4 mos.)
Sand-blasted finish					
Average	12.5 (5)	19.8 (5)	0.1 (9)	2.6 (10)	2.38 (10)
Range	6¼ to 17½	17 to 22	0 to ½	2 to 3	2 to 3½
Vapor-blasted finish					
Average	11.0 (5)	16.0 (5)	0.1 (9)	1.58 (10)	2.0 (10)
Range	10 to 13	15½ to 18	0 to ½	0 to 2½	1½ to 3
Electrolytic-blasted finish					
Average	4.3 (5)	14.6 (5)	0.1 (9)	1.38 (10)	1.18 (10)
Range	2 to 8½	12 to 18	0 to ¼	0 to 2	½ to 2½

* The removal torque in inch-pounds determined *in vitro* and *in vivo*. In the *in vitro* experiments the insertional torque was five inch-pounds in acrylic (with setting methyl methacrylate put into the drill holes during insertion), and ten inch-pounds when epoxy glue was similarly put in the drilled holes in rock maple. Holes were 3/32-inch in acrylic and 5/64-inch in maple. Numbers in parentheses designate numbers of screws in sample.

RESULTS

The *in vitro* removal torque of the screws with three different finishes are recorded in Table I. An evidently larger torque was required for screws with the sand-blasted finish compared with those with the electrolytic finish. Intermediate values were obtained for those with the vapor-blasted finish. Since the insertional torque for all screws was identical, and depth of insertion was identical, these results are deemed highly significant. The reason for the variation in removal torque could be seen on examination of the screws after removal. The grooves in the threads of nearly all the sand-blasted screws were filled with a mixture of hardened epoxy resin glue and wood or acrylic plastic. Lesser amounts of this material were present on the vapor-blasted screws, and the electrolytically polished surfaces were practically clean. In the other *in vitro* experiments with the use of type-metal or solder, approximately equal amounts of residue were found on the threads of all the screws, whereas in the wood-block experiments, no residue was found.

The removal torques in the *in vivo* experiment are recorded in Table I. While the variation is not as great as *in vitro*, the trend is the same. The reasons for lesser removal torques in these experiments, compared with those usually found in clinical situations, may be one or more of the following:

1. The screw threads were much shallower than those customarily in clinical use;

2. The depth of cortex engaging the screws was much smaller than in human bones;

3. The time periods for repair were rather shorter than is usual for the clinical removal of appliances used for fixation of fractures;

4. A tight fit is the usual desideratum when a screw is inserted in clinical fractures. Here the screw fit at operation was very loose.

The histological preparations did not show any marked difference in tissue reaction to the three surfaces. The extent of repair in general was greatest in the four-month specimen and least in the two-month group, but individual variation within groups was considerable, so that a wide range of the sequences of repair was available. Because of the design of the experiment, and its purpose, the very early phases of repair were not seen. All the specimens exhibited tissue contours approximating the profile of the screw threads; but at higher magnifications, the tissue bordering on the screws did not show contours similar to those of the different screw-surface finishes. This may have been due to one or both of the following:

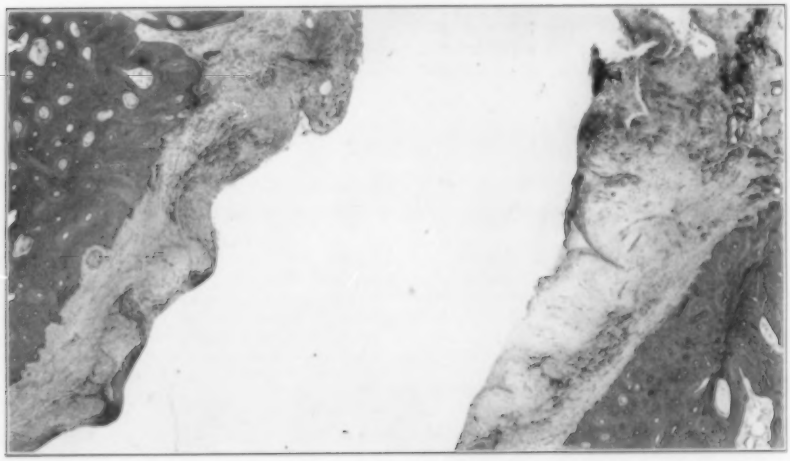

FIG. 4

Early phase of repair in cortex. Fibrous tissue surrounds screw (space), but has not yet completely filled threads. Acellular bone is present under the fibrous tissues.

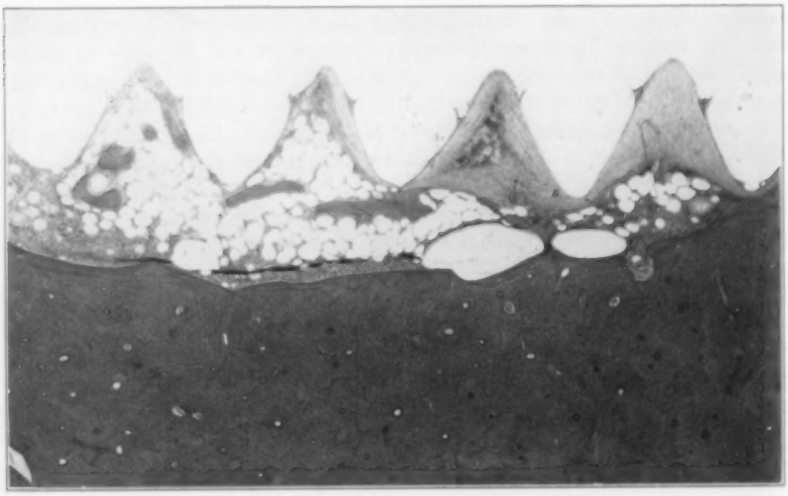

FIG. 5

Early phase of repair in marrow. Cortical bone below. Fibrous tissue in marrow has taken on thread configuration.

1. On removal, the screw surfaces slide over the tissue and would be expected to iron out minute elevations of soft tissue;

2. As demonstrated on examination of the screws, most of them brought a thin layer of soft tissue with them on removal.

On this basis it seems quite likely that a thin layer of fibrous tissue always separated metal and bone, although frequently it could not be found in the sections.

The earliest observed phase of repair, where the screw was in contact with cortex (Fig. 4), consisted in the formation of a layer of loose vascular proliferating fibrous tissue with small foci of inflammation. As the process of repair progressed, the fibrous tissue tended more and more to approximate the thread contours.

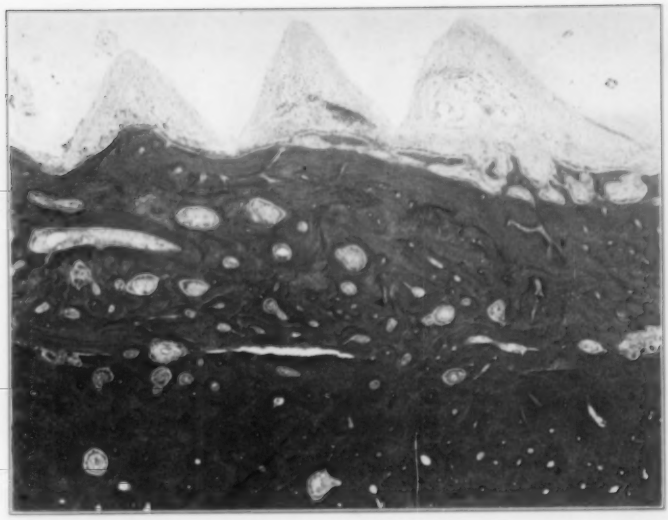

FIG. 6-A

Figs. 6-A, 6-B, and 6-C: Three later stages of cortical repair. The earliest reveals a layer of repair bone on the residua of cortex, the two partially separated by the artifactual space. Beginning bone ingrowth into screw grooves. The middle and latest stage shows further bone ingrowth. The rough surface of the latter probably indicates removal of a thin fibrous layer, remnants of which can still be seen.

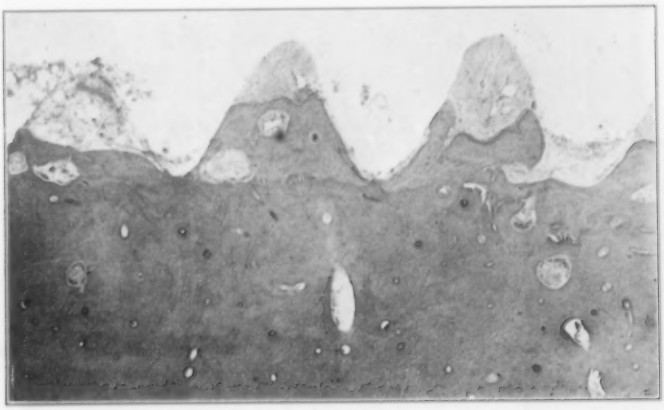

FIG. 6-B

The cortical bone beneath this layer of fibrous tissue in the cortical portions of specimens consisted of layers of appositional bone interrupted by frequent channels which were continuous with the Haversian spaces and contained fibrous tissue similar to that described. Deep to the layers of appositional bone, a variable amount of dead cortical bone (bone with acellular lacunae) occurred, not separated from the living bone by any distinctly stained boundary. The remaining cortex showed signs of extensive remodeling—that is, large Haversian spaces with seams of new bone and many osteoblasts in some areas, and resorption fronts with osteoclasts in others.

The earliest stages of repair, where the screw was in contact with marrow, were characterized by a lesser degree of fibrosis than was seen in the cortex. Often the sections showed that the fatty and hematopoietic marrow had been in direct

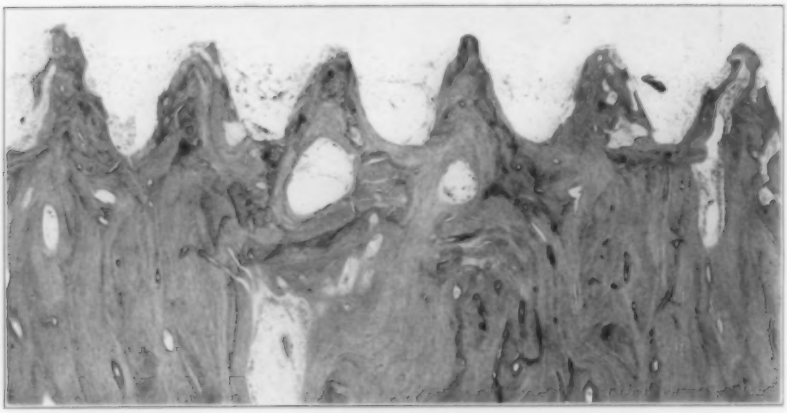

FIG 6-C

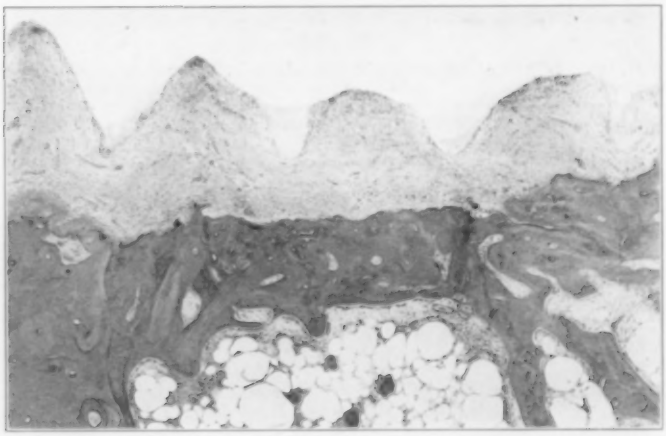

FIG. 7-A

Figs. 7-A and 7-B: Two later stages of marrow repair. The earlier shows bone underlying thick fibrous tissue filling the screw threads. The later one shows bone growing into the threads.

contact with the teeth of the screw threads, whereas fibrous tissue had filled the grooves. The tongues of fibrous tissue in the grooves often contained cells oriented perpendicularly to the axis of the screw; these cells showed progressive proliferation toward the screw (Fig. 5). No necrosis in the marrow was visible, but an occasional group of foam cells indicated absorption of areas of fat necrosis.

The later stages of repair in the cortex revealed further apposition of bone in the tabs of fibrous tissue which projected into the grooves of the screw. Sometimes the appositional bone was orderly and compact. In other instances a normal pattern of periosteal-bone deposition occurred with remodeling of the new bone into more compact patterns (Figs. 6-A through 7-B). In still other instances metaplasia of the fibrous tissue into bone preceded the remodeling process. In most cases, some residual fibrous tissue could be found at the surface of contact with the screw, and in many instances the limiting cellular boundary was smooth and several cells in thickness, resembling synovial membrane. Where the contact

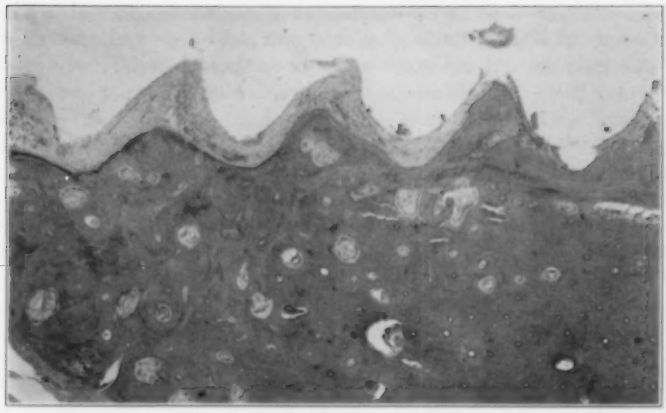

FIG. 7-B

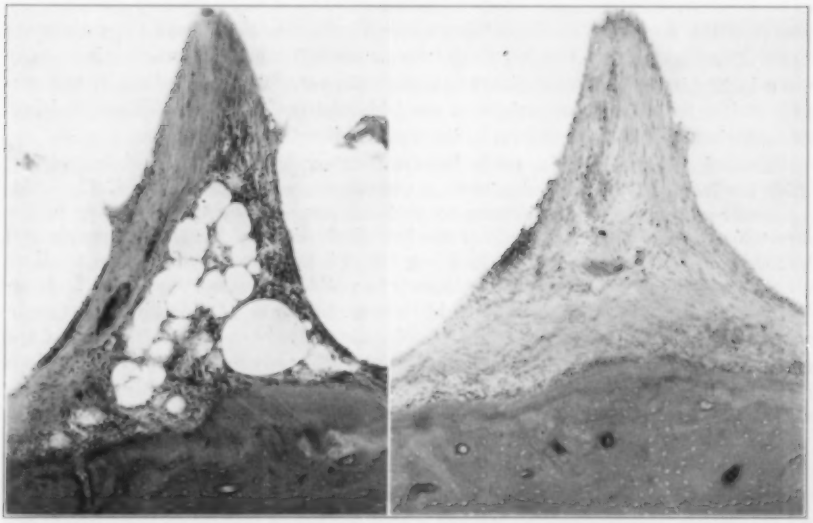

FIG. 8-A FIG. 8-B

Fig. 8-A: Projection of marrow fibrous tissue into screw thread. Note orientation of fibers. Black granules visible on their left margin.

Fig. 8-B: Projection of fibrous tissue from cortex. Black granules visible in center. Orientation of fibers shows pathology of ingrowth. Acellular bone visible at base of both specimens.

surface was bone, the outer margin often was covered with a thin layer of cells or was slightly rough as if a soft-tissue layer had been torn off.

The later stages of repair in the marrow consisted of metaplasia of the fibrous tissue into bone trabeculae which become oriented along the pattern of the screw threads. Fibrous bands interrupted these trabeculae at intervals so that there never was a continuous layer of bone adjoining the screw surface in any specimen. The marrow-bone surface had features identical with those of the repair sequences of the cortex described.

A constant feature was the presence of black granules in the repair fibrous

tissue (Figs. 8-A and 8-B) in all specimens. The granules ranged in size from several micra to the lower limit of microscopic definition and resembled small crystals. The granules did not stain for iron; no further stains were attempted. No consistent difference in the amount of granular material could be distinguished in the preparations from the three surface-finish groups. No acute inflammation accompanied the foreign material, and repair processes seemingly continued in proximity to it without hindrance.

The weights of the screws following cleaning were uniformly less than at insertion, by amounts varying between 0.5 milligram and 0.1 milligram, but none of the three surface-finish groups showed consistently greater weight losses than the others.

DISCUSSION

The object of this study was to determine what part the surface finish on a screw plays in the reaction of the tissues to the screw. From a histological point of view it was shown that the three different surface finishes used did not produce appreciably different types or degrees of tissue reaction. From the mechanical point of view, however, the coarser surface finish leads to greater difficulty in removing the screws. The deposition of repair fibrous tissue and bone thus occurred in such close coaptation to the screw surfaces that an increase in twenty micro-inches in surface deviation from the reference (nominal) plane of the surface, as illustrated by comparison of sand-blasted *versus* electropolished finishes, was sufficient to elicit considerably increased removal torque.

A distinction should be made between removal torque and holding power, which are frequently confused, although the two are entirely unrelated. The holding power of a screw, or resistance to pull-out, depends on the geometry of the screw threads and the magnitude of the interdigitations of the screw threads and the medium (bone or wood, etc.). Holding power is measured by fixing the medium in a vise and measuring the force necessary to pull the screw straight out. In practice, the holding power of screws would be expected to be at a maximum immediately after the screw is inserted and to decline slowly as bone is resorbed around the screw. In any case, holding power should not be affected appreciably by variations in surface finish. For nails, on the other hand, pull-out is appreciably affected by surface finish, particularly where the medium is compressible.

On reflection, it will be evident that different factors will influence the torque of insertion of screws. Given identical screw dimensions and surface, the torque of insertion will be affected by several conditions, some of which are: the character of the medium, the amount of medium which has to be cut away by the screw, the amount of medium which by its elasticity or plasticity is pushed aside by the screw, the lubrication between screw surface and medium, the design of the screw tip and threads, and the speed of insertion. In clinical practice, where screws are inserted into bone, perhaps the character of the medium, that is, whether the bone is cortical or cancellous, and the amount of medium (bone) to be cut away are most important, although other factors may play important roles too. Variations in the dimensions of the screw will, of course, also influence insertional torque, often to a marked degree. Important dimensional variations, besides those inherent in different designs of screws, are: uneven spacings between threads, deviations from circular cross-sections ("out of round"), bending of the axis, and the presence of burrs or flaws. In essence, these dimensional variations or imperfections require that a larger amount of medium be cut away or pressed aside during insertion of the screw. Whether the surface-finish variation, as here tested, will importantly influence insertional torque is doubtful. Under the crude condi-

tions of the present *in vitro* studies, no consistent influence of surface finish on insertional torque was evident, but it should be emphasized that the measurement of insertional torque was not an objective of the experimental plan either *in vitro* or *in vivo*, and the variations in surface finish used were not particularly pertinent.

Since the experiments were designed primarily to study removal torque, the factors which influence it should be borne in mind. Insertional torque reaches its maximum at the end of the final turn of the screw. In contrast, removal torque is at the maximum at the start of motion of the screw. Obviously, the end point of the insertional process is arbitrary, but it should be defined in such a way that stripping of the threads of the screw or medium or plastic molding of the screw head or neck is not involved. The factors which most strongly influence removal torque are the circumstances at the end of the screw insertion. These are the fit of the screw to the medium and the friction necessary to achieve this fit or to release it. Given screws of identical dimensions and identical circumstances of insertion, it is necessary to consider removal torque, on the one hand, under conditions where no changes in medium or screw have occurred and, on the other hand, under conditions where changes may have occurred either in the medium, in the screw, or in both. Superimposed on these considerations are variations in screw dimensions or surface related either to design and fabrication of the screws or to individual variations in screws; if present these variations will also strongly influence removal torque. When dimensional variations occur which are not just differences in design and not just normal production variations, but rather imperfections, and when screws are removed immediately after insertion so that no changes in medium or screw surface occur, the removal torque under these conditions may be reduced greatly compared to the torque needed to remove identically variable screws without the imperfections, because larger amounts of medium may have been cut away during insertion of the imperfect screws. When solidification of the medium is allowed to occur before removal, on the other hand, these imperfections in the screw will increase the removal torque. In these experiments it has been shown that, if solidification is sufficiently firm and well coapted to the screw surface, as was the case with the epoxy resin glue experiments, surface finish then strongly influences the removal torque. This is analogous to the solidification of the bone *in vivo*, and the results are parallel.

From these remarks, it becomes evident how important for the experiments and for clinical practice are the details of fabrication as they influence dimensional variations and surface finish. In this study the variations considered are entirely apart from screw design. Experimentally, the dimensional variations can be kept to a minimum by precision grinding and by inspection and measurement. It is not known whether specifications for screws used clinically, whatever the materials and processes of manufacture, measure up to those achieved in these experiments. For this reason it cannot be concluded from these experiments that the surface finish, as it affected removal torque experimentally, is the only factor which affects removal torque in clinical practice. Most cobalt-chromium screws in clinical use have the vapor-blasted finish used in these experiments, whereas most stainless-steel screws are electrolytically polished. However, if dimensional variations are sufficiently large, they would certainly increase removal torque more than the smaller differences in surface elevations would.

Such dimensional variations as burrs, flaws, and chips, as well as thread irregularities, "out of round" and surface defects, would then be much more important than the surface finish.

The *in vivo* experiments are of interest on two counts:

1. They provide a histological panorama of reactions of bone which, although evidently of clinical application, have not been reported previously;

2. They provide evidence that despite the benign healing process around the screws and their relative freedom from corrosion, some interaction of metal with tissue took place.

In the histological preparations, evidence of residual necrotic bone caused by the drilling persisted for at least four months. In these experiments, the holes were drilled larger than the screws rather than tight-fitting in order to show histologically the reaction of the tissues to metal surface without the possibility of microscopic variations in area of contact between screw thread and bone, in pressure between the two, and in similar details of technique. Undoubtedly, tight-fitting screws would be attended by a greater extent of bone necrosis. Despite the necrosis, healing occurred by creeping substitution of bone, formation of fibrous tissue and later bone from the viable connective-tissue elements of periosteum, Haversian systems, and marrow. Inflammation was minimal and the screws, whatever their finish, in the later stages of the experiment were all surrounded closely by bone covered with a thin layer of fibrous tissue.

What the black granular material in the repair tissue was, is an intriguing problem. Laing, in experiments in which screws were implanted in the back muscles of rabbits, did not describe any such material in the tissues, although he noted "traces" of iron salts around all steel screws and around the heads of cobalt-chromium screws which had been manipulated by steel screwdrivers. The lack of any visual evidence of corrosion or tarnish of the screws in the present experiment argues against the black granules being corrosion products, but the argument loses considerable force in view of the weight losses. Furthermore, Ferguson, Laing, and Hodge showed that when a cobalt-chromium alloy, or any metal, is implanted in tissues for three months, appreciable amounts of the metal can be detected in the nearby tissues. The weight losses in our experiments were of the same order as those reported by Laing for screws which had been touched by various screwdrivers and then allowed to remain in muscle for three months. reported Laing a gain in weight for cobalt-chromium screws *in vivo* which had not been touched by screwdrivers. In the present experiments, although contact by scalpel or forceps with the screws was minimal, it did occur, but no weight gains were recorded. The usual explanation for weight losses of the magnitude recorded is some very slight loss of metal through reactions with the surrounding medium, whereas analogous weight gains are usually explained by oxidation of the surface with resulting formation of a heavier compound at the surface compared with the unreacted original alloy. We infer, therefore, that some loss of metal into the tissues must have occurred to more than counterbalance any weight gain by surface oxidation. This loss, although in excess of the measured net losses (0.5 to one milligram), was not of sufficient significance to elicit demonstrable histological foreign-body reaction or to change the screw surface visibly. Probably the black granules seen in the repair tissue represent the lost metal, perhaps in combined form.[1]

SUMMARY

Screws of chromium-cobalt alloy and of identical dimensions but with three different surface finishes were inserted into various substances and into the bones of dogs. The torque needed to insert and remove them was measured. *In vivo*, and also in one *in vitro* setup, the highest removal torque occurred with the coarsest surface finish. Histological examination of the bone revealed the same tissue reaction to all three surface finishes. Small amounts of a black granular powder of unknown composition were found in all the sections. Weight losses were

recorded for all the screws implanted. The factors influencing the torque of insertion and that of removal of a screw were discussed.

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DISCUSSION

Congenital Absence of the Fibula

(*Continued from page 642*)

Dr. Kruger and Dr. Talbott have not encountered symptomatic phantom limb; I am sure this entity exists in patients who have had amputations after the age of ten years. Prior to this age, children will forget or lose their sensory counterpart of the amputated limb by the time they are eleven or twelve. After ten years of age, they retain their sensory counterpart and may have a phantom limb, but this must not be confused with painful phantom limb, which is an entirely different entity.

The attempt of the authors to correlate the number of rays present or absent in the foot to the degree of shortening is very interesting. Their impression today is that the foot with a normal complement of rays develops a linear discrepancy much earlier than those with deficient rays, suggesting greater deficiency in growth potential in the distal tibial epiphyseal plate when all toes are present.

Dr. Talbott (closing): In our series of unilateral absence of the fibula, femoral shortening ranging from one-half to four inches, was noted in 65 per cent of the patients. In Type III cases, the femora were noted to be affected in about half of the patients; however, in these there was usually total or partial aplasia of the femur. The decision to amputate is based on the individual case. One must consider not only the discrepancy which is present, but also that which is anticipated. We have shown in a large series of cases of unilateral absence of the fibula that the leg-length discrepancy can be expected to progress to more than three inches. We want to emphasize that when such a discrepancy exists, we believe it is preferable to revise the existing limb surgically to accept a normal-appearing prosthetic device, rather than to restrict the individual's over-all stature by operative procedures to arrest growth of the normal lower extremity. The amputation we recommend is merely removal of the fore part of the foot with preservation of the existing length and the tibial epiphysis. In some of our end-bearing amputations, we observed three and a half inches of growth of the stump during five years of follow-up. This is in contrast to an average increase of slightly over one inch in patients with below-the-knee amputations followed for four years. This end-bearing amputation is easily performed as a single-stage procedure and so far none has required revision.

Rhabdomyosarcoma of the Hand*

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Apart from epithelial tumors, primary malignant tumors of the hand are not common; in particular, rhabdomyosarcoma of the hand is so rare that its occurrence has not been generally recognized in the hand literature [1].

Since February 1957, two cases of rhabdomyosarcoma of the hand have been diagnosed and treated at Walter Reed General Hospital. Our records revealed no prior experience with this tumor. A careful study of the records of the Armed Forces Institute of Pathology disclosed seven more unpublished cases.

Review of the literature disclosed only three documented cases of rhabdomyosarcoma arising in the skeletal muscle of the hand. The first case was reported by Pack and Eberhart, in 1952; the second, by Cureton and Griffiths, in 1955; and the third, by Riopelle and Thériault, in 1956.

CASE HISTORIES

Case 1 (WRGH). In July 1957, a twenty-year-old white youth fell down a flight of stairs, striking his left hand. Shortly thereafter he noted swelling of his palm associated with two small lumps on the dorsum of his hand on either side of the third metacarpal bone. The swelling was not tender and there was no increased local temperature. He was admitted to a station hospital on November 25, 1957. On November 28, a biopsy of the lesion was performed through a dorsal linear incision. The tumor presented subcutaneously on the dorsum of the hand between the third and fourth metacarpals. It was gray and smooth and looked like ischemic muscle. It extended from the web space between the long and ring fingers to the bases of their respective metacarpals. When the tumor was cut, thin caseous fluid exuded. At the station hospital, the biopsy material was thought to be representative of Ewing's sarcoma and the patient was given 1,500 r of x-ray therapy to the left hand and forearm. He was then sent to Walter Reed General Hospital.

On arrival, he complained of pain over the left sacro-iliac joint. This was accompanied by marked local tenderness and muscle spasm. Several mobile, non-tender lymph nodes were palpable in the left axilla. Skeletal survey, including roentgenograms of the sacro-iliac joints, was normal. Review of the biopsy material at Walter Reed General Hospital and at the Armed Forces Institute of Pathology resulted in a revision of the original diagnosis to that of alveolar rhabdomyosarcoma. The patient was given further roentgen therapy to the left hand. In May of 1958 a six-by-six-inch tender left gluteal mass was present, and there were enlarged inguinal lymph nodes palpable bilaterally. Biopsy of the gluteal mass on May 5, 1958, revealed metastatic alveolar rhabdomyosarcoma. The patient received further palliative x-ray therapy, but he died on August 12, 1958, with roentgenographic and clinical evidence of pulmonary, skeletal, subcutaneous, and intraspinal metastases.

Case 2 (WRGH). A Negro man, twenty-five years old, first noted a mass in the ulnar portion of his right hand in January 1959. There was no history of trauma to this, his dominant hand. The mass gradually increased in size, and the patient sought medical care at his local station hospital in March 1959. At that time he had a six-by-three centimeter, firm mass overlying the hypothenar eminence of his right hand. The mass was not attached to the overlying skin and subcutaneous tissue. There was no regional lymphadenopathy. On March 31, the mass was excised, together with the abductor digiti quinti and the other hypothenar muscles. The mass was described as firm and meaty and was contained within the abductor digiti quinti. During the excision, all muscle was removed from the fifth metacarpal and pisiform bone. Shortly after surgery the patient was transferred to Walter Reed General Hospital.

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Miami Beach, Florida, January 6, 1961.

On admission he stated that he had lost thirty pounds between January and March 1959. Physical examination revealed a three-inch well healed scar along the ulnar border of the right hand and wrist, with brawny edema of the fingers and dorsum of the hand. A small right epitrochlear lymph node was palpable, and there was also a firm, palpable, pea-sized lymph node in the left axilla.

The biopsy material previously obtained from the hand of this patient was reviewed by the Department of Pathology, Walter Reed General Hospital, and by the Armed Forces Institute of Pathology. The material was diagnosed as alveolar rhabdomyosarcoma. The patient received x-ray therapy to the right hand and forearm. The radiation therapy was started on April 29, 1959; and, by May 14, the full course of 5,100 *r* had been completed. Thereafter, his weekly blood counts remained normal and he was permitted a convalescent leave.

On August 13, 1959, the patient returned from leave in a critical condition. He was actively bleeding from his gums and was in borderline shock for which he was given a transfusion of whole blood. His platelet count was 9,000 per cubic millimeter and microscopic bone-marrow smears obtained from the sternal marrow showed massive replacement of the normal cellular pattern of the marrow by tumor cells. Shortly thereafter the patient was given 400 milligrams of cyclophosphamide and placed on a daily regimen of fifty milligrams of prednisone and 200 milligrams of cyclophosphamide. This therapy appeared ineffective. His condition became progressively worse, and he was confined to bed. Because of his obvious moribund status this man was retired from active military service. At the time of his retirement, there was clinical evidence of metastases to the skeletal system, as well as laboratory evidence of this on bone-marrow studies. The patient died on December 4, 1959. Autopsy was performed.

Case 3 (AFIP). A nineteen-year-old Panamanian youth had an excisional biopsy of a mass on the dorsum of his left hand on October 25, 1944. There was roentgenographic evidence of involvement of the fourth metacarpal. Pathological examination revealed the tumor to be alveolar rhabdomyosarcoma.

No other information is available except that this patient died on July 23, 1946, with roentgenographic evidence of pulmonary metastases. No autopsy was obtained.

Case 4 (AFIP). A Korean man, twenty-three years old, was first seen at the Twenty-fourth Medical Battalion on July 20, 1955. At that time, an excisional biopsy of a mass on the ulnar border of the right hand was performed. For three months prior to this he had had a painless swelling on the ulnar border of the hand. An incision and drainage of the mass was attempted two months prior to biopsy and yielded blood only.

A pale, granular pseudo-encapsulated mass, six by five by four centimeters, was surgically removed from the hypothenar area. Pathological examination resulted in a diagnosis of alveolar rhabdomyosarcoma. No further data is available on this patient. He was lost to follow-up because of the exigencies of war.

Case 5 (AFIP). On May 17, 1945, a soldier, thirty-five years old, underwent biopsy of a mass in the thenar eminence of the left hand. It is not clear from the records available whether or not this mass was painful, nor is it apparent how long this mass had been present.

At surgery, a four-centimeter, yellow-white, soft tumor was found surrounded by muscle and extending deep into the palm.

The exact form of definitive treatment is unknown other than that excisional biopsy was preformed. Microscopic examination of the tissue removed revealed it to be pleomorphic rhabdomyosarcoma. The patient died on May 16, 1946, with pulmonary metastases. Autopsy was not performed.

Case 6 (AFIP). A girl, one and a half years old, had a "pimple" between the thumb and index finger of one hand at the age of one month. This "pimple" enlarged and finally broke down. When she was five months old, a biopsy of the lesion was performed. A diagnosis of alveolar rhabdomyosarcoma was made, and on January 9, 1947, the hand was amputated. One year after surgery the patient had pain in the abdomen and was found to have a right upper quadrant abdominal mass. Roentgenographic skeletal survey was negative at that time. She died at two years of age. Autopsy disclosed extensive metastases to the retroperitoneal area, the mediastinal lymph nodes, the mesentery, axillary lymph nodes, kidneys, bladder, and pericardium.

Case 7 (AFIP). A five-year-old boy was brought to a physician because of a mass on the dorsum of his left hand. The mass had been present for one year before medical aid was sought. Immediately before he was seen, the mass had begun to grow very rapidly. The tumor was excised on

September 14, 1953. Microscopically, the tumor was alveolar rhabdomyosarcoma. It extended between the carpal bones and was attached to the underlying tendons, but it did not involve the adjacent bones. Six weeks after excisional biopsy, a mid-forearm amputation was performed; the patient was discharged shortly thereafter. He was readmitted to the hospital on July 29, 1955, for biopsy of a left mandibular mass which involved the mandible, the floor of the mouth, and the upper part of the neck. The biopsy material was microscopically diagnosed as metastatic rhabdomyosarcoma. The patient then received a total of 1,800 r of radiation therapy. In January 1956, he died with roentgenographic and clinical evidence of pulmonary and cervical-lymph-node metastases. An autopsy was not done.

CASE 8 (AFIP). A white married woman, thirty-five years old, entered the hospital on November 3, 1954, because of a mass of the left hypothenar eminence. She had noted a swelling in this area for three months prior to her admission. The mass had grown very rapidly during the three weeks immediately preceding hospitalization. When first examined, the mass appeared to be attached to the overlying skin but was freely movable on the deeper tissues. On November 3, 1954, radical resection of the left fifth ray, pisiform bone, and surrounding soft tissues was performed. Grossly, the tumor was seen to lie entirely within striated muscle of the hypothenar eminence. It was yellow-white, irregularly oval, and appeared sharply circumscribed. It measured four by 1.8 by two centimeters. The overlying skin was free of tumor. Microscopically, the tumor was interpreted by pathologists to be alveolar rhabdomyosarcoma. When last seen on May 17, 1955, the patient had gross metastases to the upper part of the arm. Thereafter, she was lost to follow-up.

CASE 9 (AFIP). In May 1954, a seventeen-year-old white boy reported to the orthopaedic clinic of a large general hospital complaining of a tender swelling on the thenar eminence of his right hand. The mass had been present for one month and had been subjected to two attempts at aspiration by a local physician. On admission, there was a firm, well circumscribed thenar mass which was thought to be lipoma. On May 15, excisional biopsy of the tumor was performed. At surgery, the tumor was encountered immediately upon entering the deep fascia; it was partly covered by the thenar muscles. It appeared encapsulated and was freed by blunt dissection. The tumor cut with a gritty sensation. There were areas of hemorrhage and liquefaction that exuded a yellow-white fluid. Microscopically, the tumor was first thought to be synovial sarcoma, but on further pathological review and consultation it was found to be alveolar rhabdomyosarcoma.

The physicians caring for this boy felt that amputation would be futile, and accordingly he was given 4,950 r of radiation therapy to the right hand over a thirty-day period ending July 26, 1954.

A biopsy of an axillary node on August 6, 1954, revealed no abnormal tissue. The boy was discharged but later returned to the hospital in February 1955 with pain in his left leg, massive pleural effusion, and roentgenographic evidence of metastases to the ribs, left shoulder, left ilium, left tibia, and skull. He died on February 26, 1955. An autopsy disclosed a recurrence of the tumor in the right thenar eminence along with extensive metastases to the lungs, pleura, scalp, dura mater, and mediastinal and periaortic lymph nodes.

PATHOLOGICAL FEATURES

Primary Anatomical Site

All the tumors in this series of cases were primarily located in the hand. Six were in the left and three were in the right hand. In three patients, the tumor began in the hypothenar group of muscles, and in one of these it was stated to have arisen near the attachment of muscle to the pisiform bone; in two patients, the thenar-muscle group was the primary site of involvement; and in four patients, the tumor was found between metacarpal bones (Fig. 1). In all patients, the tumors were closely associated with skeletal muscle, and in five they were specifically stated to be actually within a muscle belly.

Metastases

Postmortem pathological material was available in Cases 1, 2, 6, and 9. In these cases, metastases were widespread: to lungs, pleura, skeleton, scalp, dura mater, mediastinum, and periaortic lymph nodes in Case 9; to pericardium, parietal pleura, diaphragm, axillary lymph nodes, mediastinal lymph nodes,

FIG. 1

Cross section of hand in Case 6 showing tumor between the first and second metacarpal bones closely associated with the interosseus muscles.

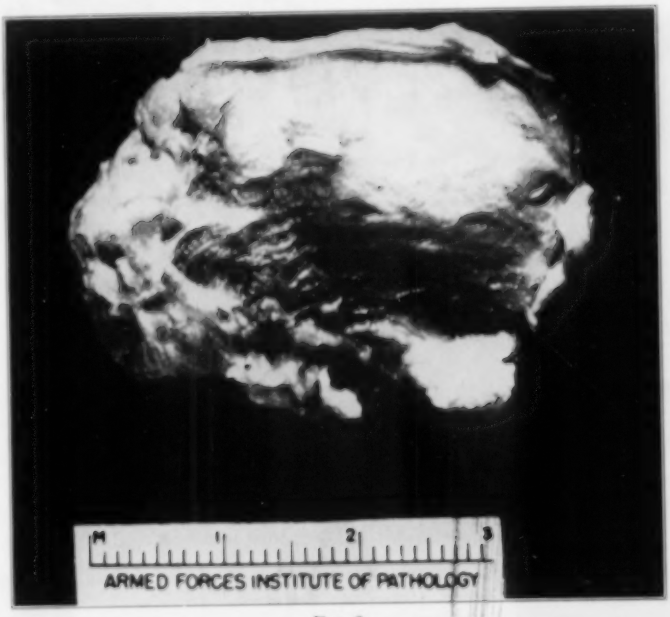

FIG. 2

Gross appearance of tumor in hypothenar muscles in Case 2. (AFIP photograph No. 59-5586.)

retroperitoneal lymph nodes, mesenteric lymph nodes, periaortic lymph nodes, pancreas, posterior surface of stomach, kidneys, urinary bladder, and adrenals in Case 6; to ribs, lungs, vertebrae, hilar nymph nodes, and retroperitoneal lymph nodes in Case 1; and to the lungs (by lymphangietic spread), heart, adrenals, spleen, pancreas, testes, bone marrow, and lymph nodes, as well as to the peritoneal

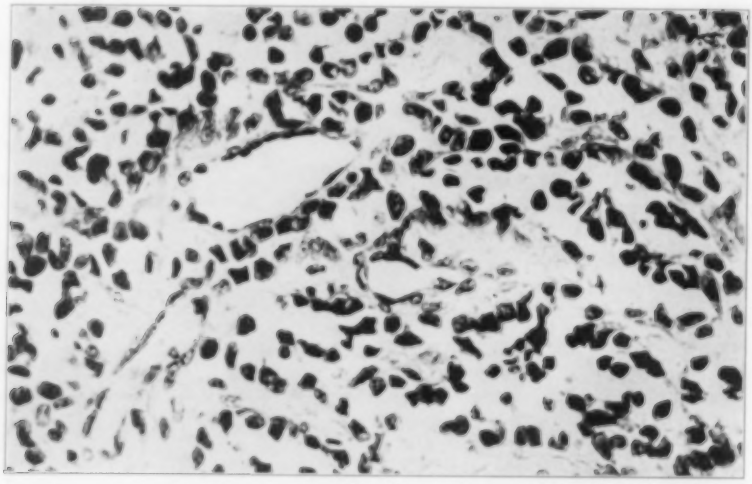

FIG. 3

Microscopic appearance of tumor in Case 2 showing its alveolar pattern (hematoxylin and eosin, × 350). (AFIP photograph No. 59-6803.)

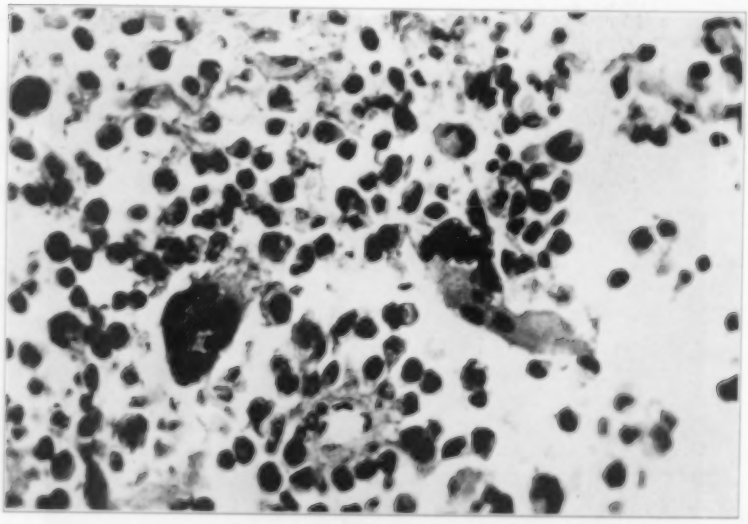

FIG. 4

Multinucleated muscle giant cells and giant myoblasts in Case 2 (hematoxylin and eosin, × 350). (AFIP photograph No. 59-6804.)

and pleural surfaces and to the subcutaneous tissues of the abdomen, thorax, and thighs in Case 2.

Gross Appearance

The tumors were usually well circumscribed but not encapsulated. They were pinkish or tan after fixation and were firm and tended to bulge from the cut surface. They ranged from two to five centimeters in diameter and appeared to replace the normal skeletal muscle in which they were situated (Fig. 2). In some of the tumors there were areas of focal necrosis, hemorrhage, and cystic degeneration.

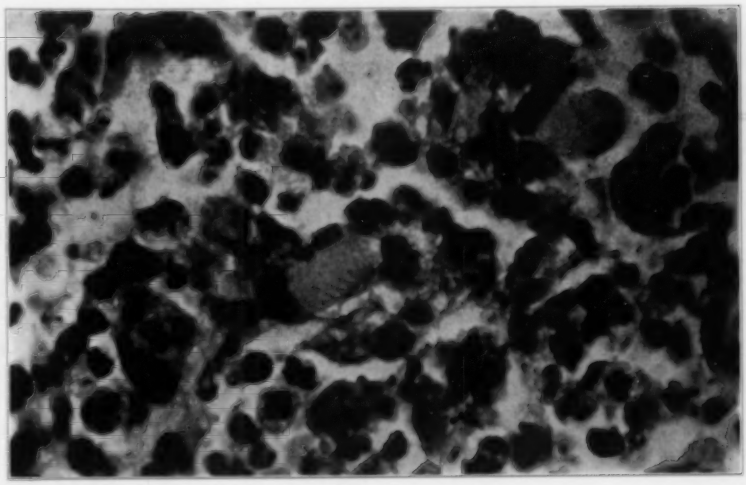

FIG. 5

Microscopic section from tumor in Case 1 showing cross striations in a muscle tumor cell (hematoxylin and eosin, × 630). (AFIP photograph No. 59-7458.)

Microscopic Appearance

All the tumors except one presented an alveolar or reticulated pattern, as described in reports by other authors [4,8] (Fig. 3). One of the tumors was pleomorphic, corresponding to the usual histological picture of rhabdomyosarcoma as described by Stout.

The eight tumors which microscopically presented an alveolar pattern were all poorly differentiated and in some areas they did not show an alveolar pattern. Their muscle origin was suggested by the presence, in some areas, of multinucleated muscle giant cells and large cells with abundant eosinophilic cytoplasm (Fig. 4). In two cases, cross-striations were found in occasional isolated tumor cells (Fig. 5). The cytoplasm of other tumor cells was elongated into strap forms and contained visible longitudinal fibers. In addition, there were zones of transition from normal striated muscle to neoplastic cells. In such areas, the sarcolemmal nuclei along the borders of definitely striated muscle fibers were hyperplastic, hypertrophic, and hyperchromatic. In many areas, the neoplasm appeared to extend into the tendinous component of the muscle. The impression was gained that the separation of individual muscle fibers or their tendinous portions by proliferating sarcolemmal nuclei produced the alveolar pattern which has been described previously. Horn and Enterline also suggested this possible explanation of the aveolar pattern. They also stated that some of the septa dividing groups of tumor cells appeared definitely fibrous, an observation which is confirmed in the present study.

Comment

With the exception of the one case of pleomorphic rhabdomyosarcoma, all of the cases presented in this report fit the description of previously reported cases of alveolar or poorly differentiated rhabdomyosarcoma. Many of these cases were seen by Dr. Richard Shuman who has made an extensive study of different types of rhabdomyosarcomata. Some were also seen by various consultant pathologists. A diagnosis of rhabdomyosarcoma was suggested as early as 1946 by one of these consultants, but it is only within the past few years that the aveolar form of rhabdomyosarcoma has gained much recognition, and even now its recognition is by no means general among pathologists.

TABLE I

SUMMARY OF CASES

Case	AFIP #	Age (Years)	Location	Therapy	Result	Survival Time after Therapy	Diagnosis
1 (WRGH)	842781	20	Between metacarpals	Biopsy followed by roentgen therapy	Dead	13 mos.	Alveolar rhabdomyosarcoma
2 (WRGH)	915642	25	Hypothenar	Excisional biopsy and 5,100 r of radiation therapy	Dead	11 mos.	Alveolar rhabdomyosarcoma
3 (AFIP)	120479	19	Between metacarpals	Local excision	Dead	21 mos.	Alveolar rhabdomyosarcoma
4 (AFIP)	718469	23	Hypothenar	Excision	Unknown		Alveolar rhabdomyosarcoma
5 (AFIP)	139382	35	Thenar	Below-the-elbow amputation	Dead	12 mos.	Pleomorphic rhabdomyosarcoma
6 (AFIP)	184274	5 mos.	Thumb web	Amputation	Dead	19 mos.	Alveolar rhabdomyosarcoma
7 (AFIP)	596761	5	Between metacarpals	Below-the-elbow amputation	Dead	28 mos.	Alveolar rhabdomyosarcoma
8 (AFIP)	681202	35	Hypothenar	Radical excision	Alive with metastases 6 mos. after therapy	Lost to follow-up	Alveolar rhabdomyosarcoma
9 (AFIP)	655818	17	Thenar	Local excision	Dead	10 mos.	Alveolar rhabdomyosarcoma
10 Dr. Pack's case		6½	Thenar	Excision (amputation was refused)	Dead	4½ mos.	Embryonal rhabdomyosarcoma
11 Dr. Cureton's case		33	Thenar	Below-the-elbow amputation	Dead	36 mos. (approx.)	Pleomorphic rhabdomyosarcoma
12 Dr. Riopelle's and Dr. Thériault's case		25	Hypothenar	Local excision followed by 2,200 r	Dead	4 mos.	Alveolar rhabdomyosarcoma

The differential diagnosis of alveolar rhabdomyosarcoma must include synovial sarcoma, neuroblastoma, malignant lymphoma, reticulum-cell sarcoma of soft non-lymphoid tissue, and alveolar soft-part sarcoma. Microscopic examination of a good section stained with hematoxylin and eosin will usually reveal some transitional zones and isolated tumor cells which have the cytological features of myoblasts. Such cells have a microscopic appearance similar to myoblasts seen in poorly differentiated areas of classic rhabdomyosarcomata of the pleomorphic type. They are also seen not infrequently in some portions of rhabdomyosarcomata which are otherwise of embryonal-cell type. The presence of such myoblasts, with or without cross-striations, in an otherwise undifferentiated sarcoma is important evidence for the diagnosis of rhabdomyosarcoma. The clinical history, primary anatomical site of the tumor, and the gross appearance give additional support.

The metastases in these cases sometimes showed an alveolar-like pattern, but unlike many embryonal rhabdomyosarcomata they did not show evidence of increased maturation. The histological diagnosis seems, therefore, to be more easily made by microscopic examination of the primary tumor.

DISCUSSION

Twelve cases of rhabdomyosarcoma (Table I) arising within the skeletal muscle of the hand have been recorded. Two of these were from Walter Reed General Hospital, seven from the files of the Armed Forces Institute of Pathology,

and three from the literature. Among these twelve cases were nine males and three females, a three to one male predominance. The age of the patients involved ranged from five months to thirty-five years, with an average of twenty years for the entire group. There was a strongly suggestive history of trauma as an etiological factor in three cases; in one patient the trauma occurred nine years before the appearance of the tumor (Case 11), while in the remaining two it occurred a very short time before recognition of the tumor—one struck his hand as he fell downstairs (Case 1) and one was hit by a hockey stick a few months before onset of the tumor (Case 12).

Four of the tumors arose in the muscles of the thenar eminence, while four arose in those of the hypothenar eminence. Four of the tumors arose on the dorsum of the hand, presumably from the interosseus muscles.

The duration of the tumor before the patient sought medical care was recorded in nine cases. This time interval varied from one to twelve months, with an average interval of four and one-half months. All of the twelve patients in this series sought medical care because of tumor of the hand. In three instances, the mass was painless; in two, the mass was definitely painful; and in the remaining seven there was no information recorded regarding the presence or absence of pain in the tumor.

In two patients there was involvement, roentgenographically, of adjacent metacarpals by the tumor. This was manifested by an irregular erosion of the affected bones. In a third, roentgenographic examination of the hand revealed a definite soft-tissue mass.

There was no single common abnormal laboratory finding in this group of patients.

Treatment and Results

In this series, four patients were treated by primary amputation of the involved hand; all four of these patients are dead. Seven patients were treated by simple local excision or radical excision of their tumors. Of this group, five patients are known to be dead; one, with known metastases, was lost to follow-up; and another was lost to follow-up immediately after the excision. One patient who was treated by radiation therapy as a primary definitive form of treatment is now dead.

Survival Times

In this series there were nine alveolar rhabdomyosarcomata, two pleomorphic rhabdomyosarcomata, and one embryonal rhabdomyosarcoma. Among those patients who died, the survival time in the alveolar rhabdomyosarcoma group (the largest single group) varied from four to twenty-eight months, with an average survival time of fifteen months. In the pleomorphic group, one patient lived twelve months and the other lived approximately thirty-six months. The one patient with embryonal rhabdomyosarcoma lived four and one-half months. It is interesting to note that the tumor in Case 6 probably represents congenital rhabdomyosarcoma, since it was noted at birth as a "pimple" on the hand, which gradually enlarged.

SUMMARY

A review of the literature has disclosed three previously reported cases of rhabdomyosarcoma arising within the skeletal muscle of the hand. Nine new cases are added to this group. Rhabdomyosarcoma of the hand is a distinct clinical entity. It is often a painless condition and is brought to medical attention only when it interferes with function or the tumor becomes too large to ignore. No suggestions for treatment are made since the series is too small to be considered au-

thoritative. However, in those patients with complete follow-up, it has been a uniformly fatal disease regardless of treatment.

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THE ORTHOPAEDIC RESEARCH SOCIETY

The next Annual Meeting of **The Orthopaedic Research Society** will be held at the Palmer House, Chicago, Illinois, on Friday, January 26, and Saturday, January 27, 1962. The deadline for abstracts is August 15, 1961. Requests for abstract forms or information concerning membership should be addressed to Dr. C. Andrew L. Bassett, Secretary-Treasurer, The Orthopaedic Research Society, 630 West 168th Street, New York 32, N. Y.

The History of Flexor-Tendon Grafting*

BY JEROME E. ADAMSON, M.D., NORFOLK, VIRGINIA, AND JAMES N. WILSON, M.D., LOS ANGELES, CALIFORNIA

To Avicenna, the famed Arabian surgeon, is attributed the distinction of performing the first operation on a tendon [12]: in the tenth century, he described a procedure for the repair of severed tendons. Yet in Europe, because of the teaching of Galen in his *Ars Parva* [18] (circa 150 A.D.), tendon repair was rarely performed. Galen had described the severe consequences from damaging or even touching a nerve or tendon and stated that a prick of a nerve or a tendon will induce convulsions. Physicians in ancient and medieval times, therefore, believed that if tendons or nerves were sutured pain, convulsions, and gangrene would result. In his writings, Galen did not differentiate between nerves and tendons but described nerves entering each muscle and noted that the muscles ended with

FIG. 1

FIG. 2

Fig. 1: Galen (131–201). (From *The Works of that famous Chirurgion Ambrose Parey*, p. 751. London, Richard Cotes, 1649.)
Fig. 2: Avicenna (980–1037). (From *Medicinhistoriens Grunddrag*, p. 64. Stockholm, 1955.)

a whitish cord. This cord was thought to be the termination of a bundle of nerves and was, therefore, called a neuron. This tendon-nerve association is still evident in the English and French languages with the expression *nervous arms*, suggesting strong arms, and *un homme nerveux*, meaning a strong or vigorous man [18]. Because of Galen's far-reaching influence, Avicenna's teachings were ignored in Europe and no attempts at tendon repair were made for 600 years.

The leaders of early Renaissance surgery of both the French and Italian schools, including Guy de Chauliac, Roger of Parma, and William of Salicet [12], practiced and defended tenorrhaphy.

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Miami Beach, Florida, January 6, 1961.

In the seventeenth and eighteenth centuries, Ambrose Paré and Andre della Croce [12], the great Italian surgeon, advocated primary repair of severed tendons: their teachings apparently resulted in some increase in the use of this procedure. However, the Galenian dogma which associated tendons and nerves and taught that they were both directly connected with the brain was difficult to overcome. In 1740, Veslingius [12] reported successful tenorrhaphy of the Achilles and patellar tendons. Severin [12], writing in support of tendon repair, stated that good union of severed tendons is much easier to obtain in children than in adults and that, because of the great extent of nature's resources in the young, repair should be attempted. The philosophy of Galen was, however, still dominant, and in the early eighteenth century, J. L. Petit [12] advised including the skin in the suture to avoid direct contact with the tendon. To avoid suturing or pricking the tendon, one surgeon [12] advocated tying a suture around each of the cut ends and bringing them together by tying the free suture ends.

FIG. 3

FIG. 4

Fig. 3: Albrecht von Haller (1708–1777). (From a portrait by Studer.)
Fig. 4: Konrad Bielsalski (1868–1930). (From *The Journal of Bone and Joint Surgery*, **12**. 448, 1930.)

In the late seventeenth and early eighteenth centuries, the Achilles and wrist tendons of the dog were first severed and successfully repaired. In 1682, Meekren [12] observed that tendons are insensitive to crushing and described the successful repair of incompletely severed tendons. He emphasized that tendons could be repaired without the dread complications of pain, gangrene, and convulsions. Soon many began to report and recommend systematic methods of tendon suture. The Galenian concept of the complications that are associated with tendon damage was finally refuted by the classic work of Albrecht von Haller [13] who, in 1752, published his work on the sensibility and irritability of the various tissues of the body and demonstrated the insensibility of tendons. Following the earlier work of Meekren, he proved the basic premise that irritability in an excised muscle is the specific innate property of all muscle tissue. The French Academy of Science approved von Haller's work and tenorrhaphy became an accepted

surgical procedure. In England, Syme reported several successful cases of tendon repair in the 1850's and from that time it has been an accepted procedure [12].

The actual transplantation of tendons was first performed in animal experiments. Gluck [8], in 1881, performed experiments designed to demonstrate the direct transplantation of muscle. The gastrocnemius muscle with its associated Achilles tendon was transferred from one chicken to another, and function of the transplanted tendon was evident even after forty days. Clinical application of these experiments was slow, but, in 1882, Heuck [16], another German physician, while repairing a defect in the long extensor of the thumb accidentally cut out a section of the tendon. The section was quickly replaced as a free graft and the patient apparently obtained a good result. Peyrot [32], in 1886, used a four-centimeter length of tendon from a young dog to repair a defect of both flexor tendons of the left long finger. Although a perfect result was not obtained, function was greatly improved. Monod [29], in 1887, transplanted a five-centimeter length of Achilles tendon from a rabbit into a defect in the long flexor of the thumb. He stated that the result of this operation was perfect, but he was not sure whether the tendon survived intact or had been replaced by a bridge of functioning scar tissue. It remained for Mainzer [23], in 1902, to report two cases in which direct homotransplants were used successfully to prolong tendons in transfer procedures. In each case, a portion of tendon from a paralyzed peroneus tertius muscle was used for transfers about the ankle.

Reports of the use of tendon transfers for correction of poliomyelitic deformities of the foot and less commonly of the hand began to appear in the literature of the early twentieth century. In an interesting article Waterman [41], in 1902, credited the Frenchman Missa with performing the first tendon transfer in 1770. The contributions of Nicoladoni, Malgaigne, Velpeau, Duplay, Tillaux, Franke, Eulenburg, and Drobnik in Europe and Milliken, Parrish, and Goldthwait in the United States, along with many others were reviewed in his historical discussion of the development of tendon transfer during this period. Velpeau [40], in 1839, and Malgaigne [24], in 1845, both recommended that severed tendons be sutured to adjacent intact tendons to reinforce those tendons still functioning. Lange, Kirschner, and Stoeffel in Germany and Hugh Owen Thomas and Sir Robert Jones in England utilized and improved on these early principles.

In Germany Kirschner [17], in 1909, and Rehn [36], in 1910, and in the United States Lewis and Davis [19], in 1911, published extensive experimental studies concerning the direct transplantation of both tendon and fascia in animals. In all these early experimental and clinical trials the thickening of the grafted or transferred tendon, as well as the adherent scarring of the surrounding tissues, was a problem of great concern—apparently an unsolvable one. Codivilla [7] of Bologna, in 1889, was apparently the first to recognize the importance of preserving the tendon sheath as a means of preventing adhesions. The advent of modern flexor tendon-graft surgery was heralded by a classic publication by Konrad Biesalski [1] of Berlin in 1910 when he reviewed the entire problem of scarring and adhesions in tendon transfers. Biesalski successfully used the autogenous sheaths of paralyzed tendons to avoid adhesions in such transfers. This work was confirmed by Henze and Mayer [14,15], in 1914 and 1915, after extensive experimental investigation performed while they were working with Lange in Munich in 1912.

Apparently the first series of free flexor-tendon grafts in the hand was reported by Erich Lexer [20], of Jena, in 1912. In his group of ten patients, he used free tendon grafts to repair flexor tendon after rupture, old lacerations and infections, and in "hopeless cases" of ischemic contracture. In seven patients he

replaced both the sublimis and profundus tendons with fair results. In two patients the profundus only was replaced: the result was so satisfactory that neither patient returned for the proposed second-stage sublimis graft. One interesting patient was an old pensioner of the Franco-Prussian war in whom flexor-tendon grafting had been successfully done but who refused further reconstruction for fear of losing his monthly government stipend. Some of Lexer's follow-ups were of two years' duration.

For donor grafts Lexer preferred the palmaris longus but also used the toe extensors. Frequently, he would transfer adjacent flexor tendons instead of using the more hazardous free tendon graft. He emphasized the importance of avoiding adhesions by careful suturing and early motion six days after operation. The anastomosis of the graft was placed at some distance from the skin incision, and local skin flaps were shifted to prevent skin-to-tendon scar adherence; the need for long and patient postoperative care was stressed. Direct attachment of the graft to a bone flap was discussed. A U-type nail driven through the distal tendon into bone, with the periosteum sutured over it, was used to attach the tendon. Although he did not indicate the importance of associated nerve repair, he recommended removal of scar and suggested rotation of flaps to obtain good skin coverage. His greatest complications were those secondary to stiff fingers and joints. In some patients, in whom scarring prohibited successful tendon-grafting, he performed arthroplasties of the proximal joints and secured good soft-tissue coverage with skin grafts as a first stage. Lexer remarked that this type of surgery was fraught with complications and difficulties, but he urged that more surgeons attempt free tendon-grafting in the hope that some of these difficult problems could be solved.

The stage was thus set for the excellent work of Leo Mayer. In 1916, he published three articles [26,27,28] which have served as the basis for the present-day concepts of reconstructive flexor-tendon surgery. Mayer reviewed the great disagreements among the proponents of tendon surgery at that time and presented detailed reports of his investigations performed in an attempt to prevent the stiffness and scar adhesions which had been bothering all surgeons working in this field. These experiments verified the principles presented in the work of Biesalski. Mayer stressed how little of the physiology of tendon function was known and presented detailed anatomical studies of the tendon, its sheath, and surrounding associated structures. He described the blood supply of tendons and outlined his concept of tendon and tendon-sheath motion. The role of mesotenon, paratenon, and the sheath in tendon function was emphasized. During the same studies, he made a classic contribution in his successful attempts to determine during anesthesia the proper tension at which tendon suture should be performed. Much of his work was done on the foot and ankle. He outlined the need for an exacting operative technique which he labeled the *physiological method*. Several important dicta were discussed in his articles: (1) direct anastomosis of tendon to bone, (2) the physiological technique in tendon repair, (3) use of an adequate muscle as a motor, and (4) the necessity of having paratenon around a flexor graft, especially in areas where it glides over damaged periosteum or cut fascia. He also advocated inverting fascia and covering it with paratenon if possible to reconstruct a gliding surface. Mayer emphasized the basic concepts of tendon transfer and noted that these concepts were applicable to free tendon-grafting as well. Three rules for postoperative care were given: (1) the operation should never be undertaken unless the surgeon himself could perform effective postoperative care, (2) early motion should be instituted at the right time, and (3) graded exercises should be used with protective splints.

FIG. 5

FIG. 6

FIG. 7

Fig. 5: Erich Lexer (1867–1937). (From *Deutsche Zeitschrift fur Chirurgie*, **203-204**: Frontispiece, 1927.)

Fig. 6: Leo Mayer.

Fig. 7: Sterling Bunnell (1882–1957). (From *The Journal of Bone and Joint Surgery*, **39-A**: 1409, 1957.) (Courtesy of Mrs. Sterling Bunnell.)

With this basis all was ready for the outstanding article, published in January 1918, by Sterling Bunnell [3]. Bunnell reviewed the anatomy and physiology of tendons and the importance of paratenon and fat in the formation of an adequate gliding mechanism and, especially, in developing a smooth frictionless pulley at joints. He mentioned how he had performed flexor-tendon grafts with apparent good results and then how he had, in five to six weeks, watched them become fixed in scar. In this study, which is a landmark, Bunnell outlined his atraumatic technique. Perfect asepsis, a bloodless field, steady light-fingered and careful assistance, and stringent precautions to avoid damaging tissues served as the basis for his operative philosophy for surgery of the hand. He also advocated a mid-lateral incision and condemned the median longitudinal incision with its obvious complications. He mentioned the need for preserving pulleys in the fingers and described the clever use of a ring on the proximal segment of a finger to serve as a pulley, if needed. His postoperative plan for immobilization and active motion, starting approximately three weeks after operation, was established. He also

preferred the palmaris tendon as a graft and advocated careful atraumatic suture, specifying the proximal portion of the palm as the ideal location. In this article he described a tendon clamp to facilitate careful end-to-end suture and the need for a full-length, palm-to-distal-phalanx graft. An ingenious modified cork borer was described as a tendon stripper which he used for removing damaged tendons; much emphasis was placed upon the necessity for the exclusion of raw surfaces from the graft bed.

Bunnell, in 1921 [4], published a more elaborate discussion of his atraumatic technique. In this plea to place surgery of the hand on the highly technical level that this specialty deserved, he reviewed the studies of time and motion in industry which had successfully improved the efficiency of workers. He illustrated his point by giving as an example the jeweler working at his well lighted, well braced, solid table with his elbows resting in a comfortable position and his hips and thighs braced firmly in a comfortable seat. The importance of calm, non-moving assistants was ranked equally with sharp instruments and good lighting. The factors of infections and long operative time were reviewed with reference to damage of the tissues in a discussion of wound healing and its importance in hand surgery. Again, in 1922, Bunnell [5] reviewed the problem, added his method of atraumatic suture, stressed the importance of proper incisions, good preoperative joint function, careful postoperative care, and re-emphasized the philosophy of his atraumatic technique.

During this period the old problem of adhesions in tendon surgery was attacked anew by Henze and Mayer [14,15], who in 1914 and 1915 published two articles on experiments in which they ensheathed tendons with fat, fascia, vein, cartilage, petroleum jelly, silver tubes, and even Cargile membrane. Unfortunately, the adhesions were worse in every case except the cases in which Cargile membrane had been used, and in these there was no real improvement in the results. In the following years many unsuccessful attempts were made to reconstruct some type of artificial tendon sheath to prevent the scarring and limitation of motion which so frequently occurred after tendon-grafting. Wheeldon [42], in 1939, described the use of cellophane as a permanent tendon sheath to prevent adhesions. McKeever [22] suggested the use of a special non-irritating type of cellophane placed between tendon and old scar and at joint regions to prevent scarring and adhesions. Thatcher [39], also in 1939, advocated the implantation of stainless-steel rods in an attempt to allow the hand to form surrounding sheaths with synovial-type linings to receive second-stage flexor-tendon grafts. Adhesions of the graft to the newly formed sheath at various points invalidated this type of procedure. Pinkerton [33], in 1942, published his views concerning the unsuccessful use of aminoplastin as a buffer for the prevention of scar formation about flexor grafts. Gonzalez [9], in 1949, reported the unsuccessful use of polyethylene tubes for flexor-tunnel reconstruction. Recently, Peacock [31] reported the grafting of a full flexor tendon and its enclosing sheath as a physiological unit.

Much of the controversy concerned with postoperative care of the grafted flexor tendon was based upon attempts to prevent the formation of adhesive scar. In 1941, Mason and Allen [25], in an attempt to demonstrate definitely the correct time for motion of the grafted tendon, reported extensive studies of the rate of healing of tendons. Their conclusions suggested that the tendon-healing rate, as demonstrated by its tensile strength, conformed directly with the three stages of tendon healing which had been previously reported. In the first phase of exudation and fibrinous union, there was rapid diminution in the tensile tendon strength which usually lasted about five days. Following this a phase of fibroplasia occurred which was coincident with a marked increase in tensile strength and which con-

tinued until approximately the sixteenth day after repair. At this time a gradually progressive increase in strength developed, associated with a phase of maturation or so-called organizing differentiation. These conclusions of Mason and Allen led to the concept that motion in the grafted tendon should not begin until the latter part of the second or the first part of the third week after operation.

Quite naturally, when early scarring and stiffness in tendon-transfer procedures in the late nineteenth century led to non-function, surgeons turned to the use of artificial tendon substitutes. Catgut, silver wire, and silk sutures were used extensively. The silk tendon, as employed by Lange [18], yielded very good results in transfers for the restoration of function after paralysis caused by poliomyelitis, but Lange was the first to admit that in many cases dense scar tissue frequently led to strong limiting adhesions. Graham [11], in 1955, reported his unsatisfactory experiences with the experimental use of frozen stored tendons for grafting. In 1956, Sarkin [27] emphasized the obvious truth that, despite careful technique, many cases of flexor-grafting did not do well and described his plastic replacement for flexor tendons. He reported good function with the use of plastic tendon replacement, even in the face of open primary wounds. There was minimum postoperative morbidity, but no long-term evaluation of his cases was reported, and no subsequent reports have been published of similar success with his prosthesis. However, Sarkin emphasized the need for further work on the ever-present problem of scarring and presented a new approach to this problem.

In 1944, the most comprehensive textbook of surgery of the hand ever written was published by Bunnell [6]. This extensive, thorough review of hand surgery has served as the basis for our present concepts of this specialty. In the First Edition he described his now classic pull-out wire suture technique. The success of this technique was confirmed by Moberg [29], in 1951, when he reviewed 101 cases in which this pull-out wire technique had produced "remarkably good results, especially when suturing tendons and ligaments to the skeleton".

During the past decade progress in flexor-tendon grafting has been marked by various technical advances and differences of opinion as to the best technique and changing concepts as to the indications for grafting. Leaders in the field throughout the world have published numerous authoritative experiences with free flexor-tendon grafts. In the United States, Graham [10] and Littler [21], in 1947, and Boyes [2], in 1950; in England, Pulvertaft [34], in 1948; and in Australia, Rank and Wakefield [35], in 1952, joined many others in reviewing the principles of flexor-tendon grafting. It is obvious from the many different techniques and the limited number of completely successful results that the ideal method for the restoration of flexor-tendon function has not yet been achieved. The challenge of the unsolved problem of attaining good gliding function of the free graft while preserving an adequate blood supply through adhesions still remains. As was known to Lexer, Biesalski, Mayer, and Bunnell, the control of scar tissue continues to be the greatest problem in flexor-tendon grafting.

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Injury of the Median and Ulnar Nerves

One Hundred and Fifty Cases with an Evaluation of Moberg's Ninhydrin Test *

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Some years ago, one of us reported the results in a series of cases after suture of the radial nerve. In the discussion which followed, a surgeon commented that it was a simple matter to secure good results from suture of the radial nerve, but he said that he would like to know what the results are after suture of the median and ulnar nerves.

During the past years we have operated on several hundred patients with injuries of the median, ulnar, and digital nerves. From this group we have chosen 150 cases for our present study. The selection of cases was based on the level of injury and the amount of tissue destruction. Because regeneration after high peripheral nerve lesions is not as complete as after more distal injuries, cases of injury above the middle of the forearm were not included. Injuries with marked tissue loss and destruction were also not included because these were frequently complicated by long-delayed operation, multiple operative procedures, or inability to obtain end-to-end approximation of the divided nerves without excessive tension.

The excellent paper of Moberg encouraged us to re-examine a number of our cases with the aid of the tests Moberg described, particularly the ninhydrin fingerprint test and the picking-up test. Previously, we were accustomed to evaluate postoperative results by the routine tests of pinprick, light touch, and temperature perception, and by the ability of the patient to return to his job. Moberg in his study was astonished to find patients whom he considered to have good function after nerve suture unable to button their clothing, wind a watch, put a nut on a bolt, and to perform other simple tests requiring grip with precision. Moberg coined the term *tactile gnosis* to describe the sight-like function of the normal hand, a function which is lost, however, after a nerve injury.

Surgeons have long needed objective methods of examination and evaluation after nerve injury and nerve repair. Moberg believed that both the picking-up test and the ninhydrin fingerprint test are objective and permit a more accurate evaluation of functional return than do simple subjective tests. From his studies he concluded that sudomotor function and the higher qualities of sensation in the hand bear a close correlation and not only are both lost together at the time of nerve injury but both return together with regeneration after nerve repair. The present study was undertaken to corroborate Moberg's results with the ninhydrin test and to determine if sudomotor function and useful sensation do, in fact, return together.

It is our impression that sudomotor function does not return to an area supplied by a divided nerve unless that nerve is sutured. We have observed three patients in whom nerve suture had not been done but in whom nerve division was

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Miami Beach, Florida, January 6, 1961.

TABLE I

DATA ON 150 NERVE INJURIES

Nerve Injured	No. of Injuries
Median	46
Ulnar	32
Median and ulnar	13
Digital	59
Total	150

TABLE II

TIME LAPSE BETWEEN INJURY AND NERVE REPAIR

Nerve Injured	Time Lapse		
	8 to 10 Hrs.	1 to 6 Mos.	6 Mos. or More
Median	7	26	13
Ulnar	3	11	18
Median and ulnar	3	4	6
Digital	14	21	24
Totals	27	62	61

later confirmed. They showed anhydrosis at one and one-half, two, and two and one-half years, respectively, after injury.

Table I lists the different nerves injured and the number of injuries in each category. The youngest patient at the time of surgery was a girl of eighteen months; the oldest was a man of sixty-two years. The group includes twelve children under the age of ten years. There were 122 male patients and twenty-eight female patients. All were re-examined by one of us. The longest follow-up was twenty-four years; the next longest, nineteen. Of the 150 patients, thirty were examined five or more years, fifty-one two to five years, and seventy-nine less than two years after nerve suture.

Table II shows the time lapse between injury and nerve repair. Nerve suture was performed at the time of the injury—that is, within eight to ten hours—in twenty-seven instances. Sixty-two patients were operated on within six months after injury, and the remaining sixty-one patients were operated on more than six months after injury.

METHOD OF EXAMINATION

We were interested to learn each patient's own evaluation of the results. In response to inquiry concerning the ability to regain their former status both in employment and in recreational pursuits, almost all patients said that they had returned to their former activities, either because of a good result or because the injury was not in itself a handicap. Other patients, however, had to resort to new techniques or methods (Fig. 1-A). Children seemed to regain normal function more rapidly and more completely than did adults.

The examiner also gained a good deal of information by inspection of the part (Fig. 1-B). The presence or absence of dirt, stains, or calluses frequently proclaims usefulness or disuse.

When examining for light touch, cotton applicators were applied to an area with normal sensation while the patient's eyes were closed, and the pressure was

FIG. 1-A

FIG. 1-B

Fig. 1-A: Division of the median and ulnar nerves in the middle of the forearm due to a penetrating wound of the forearm resulted in loss of substance of both the median and ulnar nerves. Incomplete regeneration of both nerves is shown by intrinsic-muscle wasting and return of sensation of gross grip only. Note how the patient uses the adjacent sides of the thumb and index finger, which are innervated by the *radial* nerve, to pinch, rather than attempting to use the insensitive tips of the digits.

Fig. 1-B: A callus is outlined on the dorsomedial surface of the thumb overlying the distal joint. Even though the patient is a laborer, he prefers to use the more sensitive and yet less strong grip, as illustrated in Fig. 1-A, which has produced an obvious callus.

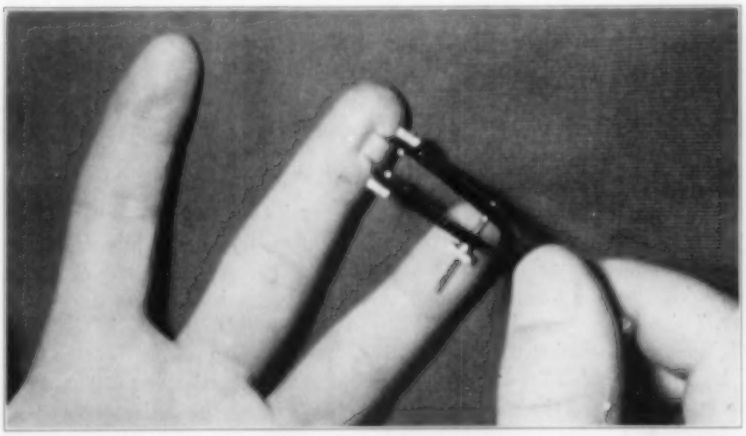

FIG. 2

Demonstration of Weber's two-point discrimination test using an adjustable sharp-pointed divider.

increased until he could just perceive a touch. With use of the same amount of pressure, the involved part was examined, and the patient asked to respond when the stroke was felt.

When testing for pinprick, the patient was asked to differentiate between the dull and sharp ends of a safety pin when his eyes were closed. The inexperienced examiner should be cautioned not to touch a patient with a pin and ask, "Do you feel that?" Even in the presence of a complete nerve lesion, the patient will be aware of the stimulus and answer "yes". The examiner then concludes the patient felt the pinprick and assumes that the part has normal sensation. One must be certain to ask about the sharpness of the point and to compare the effect of the pinprick with that on a normal zone.

In our series, Weber's two-point discrimination test appeared to be a reliable

indicator of the completeness of regeneration. Two conditions are essential in carrying out this test: the patient must be cooperative and the examiner must be consistent and skillful. A five-millimeter spread of the divider points was assumed to be normal perception on the finger tip, and readings greater than twenty millimeters indicated that this modality was absent (Fig. 2).

Tinel's sign—that is, paresthesiae or formication along the course of the nerve caused by gentle percussion over the nerve distal to the line of suture—was sought in most cases. This test is of limited value but it does serve to indicate continuity across the line of suture early in the postoperative course. It generally becomes positive four to six weeks after nerve repair. By careful percussion and observation, one may be able to plot the progression of nerve regeneration, but the quality of returning sensibility cannot be determined.

Finally, sudomotor function was tested by the ninhydrin printing test after the method of Moberg. An impression of the finger tips is taken on a clean piece of paper, and the finger is outlined with a pencil. White paper that has not been contaminated by previous handling is satisfactory. Moberg was kind enough to supply us with several pads of the type of paper * he uses in his examination and we have obtained the clearest prints using this paper. It is neither too glossy nor too porous and is guaranteed not to have been touched during packaging. It has a perforated margin by which it can be handled and on which the patient's name and other data can be recorded. After the fingerprints are obtained, the paper is immersed in 1 per cent ninhydrin solution and then hung up to dry. Good prints will appear in an hour or so, but if more rapid developing is desirable, the paper is placed in an oven at 120 degrees centigrade for ten minutes.

The prints are fixed for permanent record with a solution of copper nitrate. A delay of two or three days is recommended to allow the prints to become fully developed before they are fixed.

It may be difficult to be sure of the lack of sweating on one side of the finger, unless the finger is carefully outlined and the prints of the other fingers are clear for comparison. Haymaker and Woodhall stated that autonomic fields are less constant than sensory fields. If this is true, it is reasonable to expect some difficulty in interpreting a nerve lesion of a small area, such as half of the pulp of the finger. This places a certain limitation on the printing procedure in the diagnosis of digital-nerve function unless the prints are of good quality.

Moberg's picking-up test was added to the examination in patients in whom there were lesions of the median nerve and injuries of the digital nerves to both the thumb and index finger. This test, more than any other, demonstrates the presence or absence of tactile gnosis. There were seventy-one patients to whom this test was applicable—forty-six with median, thirteen with combined median and ulnar, and twelve with combined thumb and index digital-nerve lesions. Only ten of these seventy-one patients regained normal or near normal tactile gnosis. Tests of a child's ability to pick up objects, conducted by the parents at home, were useful in the very young patient to evaluate the preciseness of touch.

INTERPRETATION OF RESULTS

The extent of recovery obtained after nerve suture depends on many factors. Much of our present knowledge concerning the many facets of nerve regeneration has been gained from work done on laboratory animals [2,3,10]. It is difficult to compare experimental data with those obtained from clinical studies. We do not

* Purified paper for ninhydrin printing test for sensation, manufactured by Gransholms Aktiebolag, Gemla, Sweden.

TABLE III

THE RETURN OF SENSATION ONE OR MORE YEARS AFTER NERVE SUTURE

Nerve Injured	Pinprick	Sensation		
		Light Touch	Two-Point Discrimination	Tactile Gnosis
Median (46)	44	44	4	4
Ulnar (32)	28	28	1	0
Median and ulnar (13)	12	12	3	3
Combined thumb and index digital (12)	12	12	3	3
Other digital	47	47	2	0

often encounter in a patient the favorable conditions that are present in the laboratory animal. The accidental wound is seldom comparable to that produced by the kindly swipe of a surgeon's knife. Infection, long delay in healing, extensive destruction of soft tissue, vascular injury, and failure of previous attempts at repair, all result in scar formation. In neglected cases, nerve ends are often widely separated so that a considerable amount of dissection is necessary before end-to-end anastomosis can be accomplished. Even then, we are often forced to suture nerves under more than normal tension. The accidental wound may divide a nerve at a point where the nerve divides into separate branches. In such cases two or more distal segments must be united to the proximal nerve. We have been able to minimize this problem to some extent by our selection of cases and, in particular, by the elimination of cases in which the damage or loss of tissue was great.

Table III summarizes the results of testing for the various modalities of sensation after nerve suture. A definite impression that we have obtained from the results of the pinprick test is that return of sensation is much slower than is generally believed. None of the adults followed for less than five years regained normal or near-normal sensation, whereas the children regained normal sensation during the second year after nerve repair. From the data in the patients' records, it is not possible to estimate the rate of recovery, but it was evident that significant return of sensation to pinprick did not develop in any instance in less than six months. Response to pinprick was invariably noted between one and two years after median-nerve suture.

There was close correlation between Weber's two-point discrimination test and the picking-up test. In only three adults did two-point discrimination return to normal, but two-point discrimination returned to normal or almost normal in all ten children old enough to cooperate in the examination.

The picking-up test is one of great value in determining the functional value of the hand in median-nerve lesions. It is easier to do, is less time consuming, and is more objective than is the two-point examination. The picking-up test can also be used in digital-nerve lesions involving the thumb and index finger but is of little or no value in ulnar-nerve lesions with intact sensation of the thumb. The test, if sensation is intact in any one of the fingers used in the maneuver, does not give a true picture of the status of tactile gnosis in the other fingers.

The earliest appearance of sweating occurred five months after nerve suture in three cases of digital-nerve lesions. In most instances, it became apparent in from seven to twelve months. With the return of sweating after nerve suture, the dots in the ninhydrin test were irregular in size and distribution as compared with the normal finger-tip pattern. In most cases, ample sweating was demonstrated after from one to three years, but the prints did not resemble normal prints. In patients followed for five or more years after suture, the prints resembled more

FIG. 3

Ninhydrin print which shows anhydrosis in the median-nerve distribution of the left hand because of a complete division of the left median nerve at the wrist. Note the printed areas on either side of the thumb which are due to normal radial-nerve innervation. The right hand is shown above for comparison. The prints have been photographed on red-sensitive film (Duplo Ortho, Gevaert) in order to accentuate the dots which appear light red after fixing with copper nitrate.

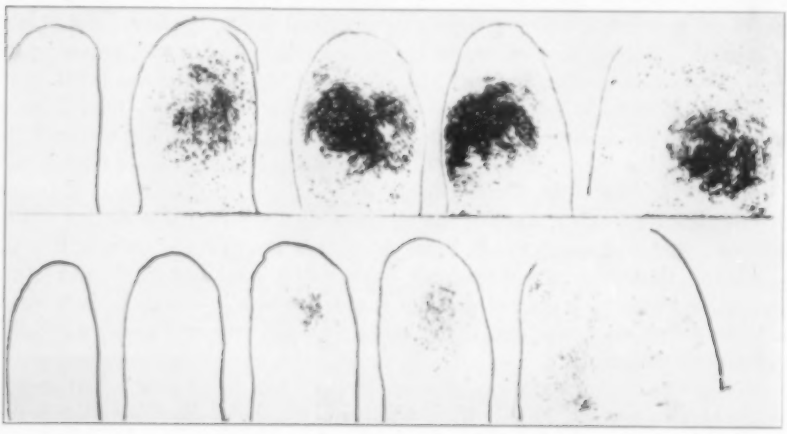

FIG. 4

Ninhydrin prints in two cases of division of the ulnar nerve. The upper print shows absence of sweating over the classic ulnar-nerve distribution, and the lower print shows a common variant in which the ulnar-nerve supply included the ulnar two and one-half fingers.

closely the normal pattern. Children showed the most rapid and most complete return of the printing pattern. One child had normal sweating at the end of thirteen months. The children followed for less than one year did not have complete return of sweating, but in all those followed for two years or more sweating was normal.

There was a correlation between return of response to pinprick and return of sweating. Neither returned independently of the other, although the return of one was often of greater magnitude than that of the other. Correlation between sweating and the return of tactile gnosis was very poor. After a successful nerve suture, sweating invariably returned; but tactile gnosis did not return in some, and was greatly diminished in the majority of patients. In only three of the adults did the precision grip return completely or almost completely.

FIG. 5

Three examples of ninhydrin prints of digital-nerve injuries. From above down, the prints portray division of the ulnar digital nerve to the long finger, of both digital nerves to the index finger, and of both digital nerves to the thumb.

As seen in Table III, most patients regained sensations of pinprick and light touch. Only a few regained normal two-point discrimination, and fewer still regained tactile gnosis.

THE NINHYDRIN PRINTING TEST

Our impression of the usefulness of the ninhydrin printing test in relation to other methods of testing for nerve lesions can be shown by the prints made in some representative cases.

It should be emphasized that the ninhydrin test is extremely sensitive and that special care is necessary to prevent contamination of anesthetic areas by the patient's or the examiner's hands. On occasion, prints were obtained that were too light for interpretation, but the main problem associated with the performance of the test was contamination of the finger tips by extraneous sweat and false positive tests. Figures 3, 4, and 5 are examples of complete nerve divisions and demonstrate how the ninhydrin printing test can be used to yield a precise record of an area of anhydrosis and, therefore, an area of complete anesthesia.

In cases of acute nerve injury there is a very definite advantage in having an objective method of examination at one's disposal, as the patient is often uncooperative because of anxiety, age, mentality, or language. In a one-year-old infant who suffered a penetrating wound of the thenar eminence, the ninhydrin print of the thumb (Fig. 6) showed lack of sweating on the ulnar side of the thumb. On this evidence the wound was explored, and the divided nerve was sutured.

There still remain many deficiencies in our ability to evaluate quantitatively the result of a peripheral nerve repair. The ninhydrin test has been championed by Moberg as enabling the examiner to differentiate between a poor, a mediocre, and a good result as far as sensory return is concerned. In Figure 7, the ninhydrin prints of two patients with median-nerve repair are shown. The upper set repre-

sents a man of sixty-two years who had a division of the median nerve at the wrist nineteen years before which was sutured a few hours after injury. He maintained that his hand was perfectly normal. There was no motor defect despite considera-

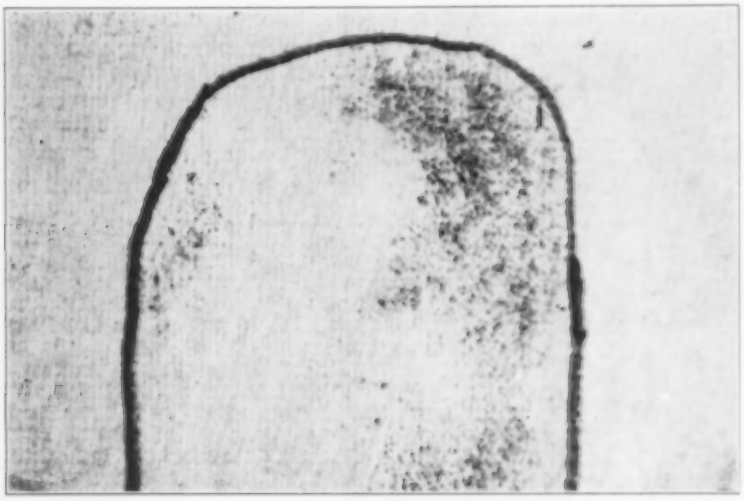

FIG. 6

Ninhydrin thumb print of a one-year-old infant with a penetrating wound of the thenar eminence. Except for a few dots due to radial-nerve innervation on the extreme border of the thumb, the ulnar side of the thumb is devoid of dots owing to division of the digital nerve.

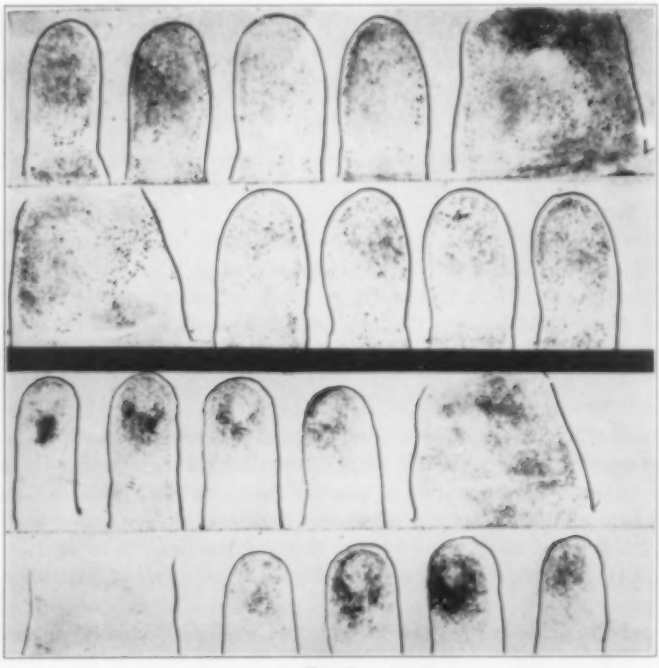

FIG. 7

Ninhydrin prints of two cases of suture of the median nerve. The upper print of each pair represents the normal (left) hand; the lower print is of the injured hand. In both cases, the quality of the prints of the normal and injured hands are comparable (see text for explanation).

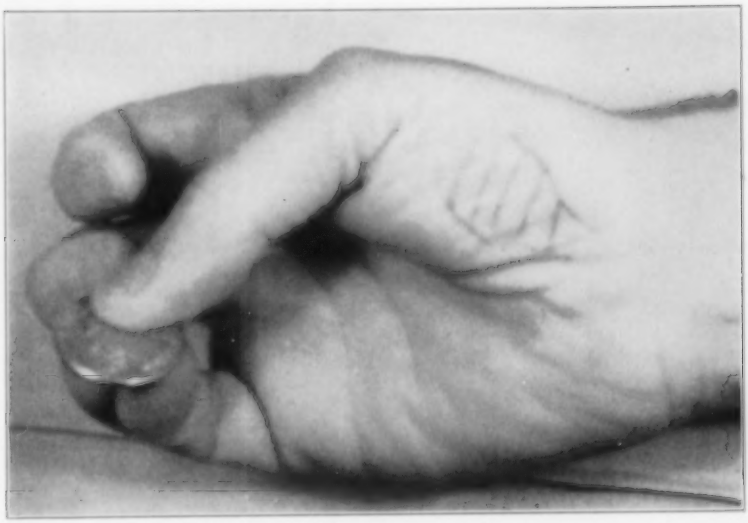

FIG. 8

The right hand of the patient whose ninhydrin prints are shown in the upper pair in Fig. 7. An area of thenar wasting is outlined. The patient has picked up a coin with his eyes closed and does so by using the normally innervated ulnar fingers.

FIG. 9

Ninhydrin print made twenty-four years after repair of the ulnar nerve of the left hand. The upper print is of the normal (right) hand. Although sweating is present within the ulnar-nerve distribution on the injured side (lower print), it is less pronounced, at least, on the ulnar side of the ring finger.

ble wasting of the thenar muscles, and the prints of each hand are certainly comparable. Pinprick and light touch were felt normally, but two-point discrimination was greatly impaired compared with the normal side. Blindfolded, he was able to perform the picking-up test with the involved hand (Fig. 8) but much more slowly than with the normal hand, and identification of the objects while blindfolded was good but not perfect. In other words, even though the patient could not distinguish the difference between the normal and the injured hand, and even though the

FIG. 10-A

High-voltage electrical contact burn to volar surfaces of the long, ring, and little fingers. Treatment consisted in excision of the burned tissue and closure of the ring finger by a cross-finger flap and of the little finger by a transposition flap from the dorsum of the same finger. It was necessary to expose the neurovascular bundles and tendon sheaths of both fingers at the time of excision of the burned tissue.

ninhydrin prints were not different, there was, nevertheless, a neurological defect.

The lower two prints are those of a girl of nine years who had a median-nerve suture six years before. Sensory and motor examinations were within normal limits, and the ninhydrin tests of the two hands were comparable, as shown here. Thus, the ninhydrin prints of each of these patients produced evidence of nerve regeneration after nerve suture, but did not help in the estimation of the quality of the sensory return.

It is conceivable that a careful study of good ninhydrin prints might allow one to evaluate the quality of sensation. The prints shown in Figure 9 are those from a patient who had the ulnar nerve of the left hand sutured twenty-four years before. Examination of the hand showed excellent intrinsic function, with no evidence of clawing or intrinsic-muscle wasting. Sensation, however, was limited with hypesthesia to pinprick and no accurate appreciation of light touch on the little finger and ulnar half of the ring finger. Although the distribution of sweating is somewhat similar in each hand, the ninhydrin prints suggest an area of relative anhydrosis over the sensory distribution of the ulnar nerve of the left hand.

The very fact that sweating may occur in the absence of higher qualities of sensation has proved of considerable value in offering a prognosis in incomplete nerve division. The patient whose hand is shown in Figure 10-A suffered a high-voltage electrical burn of the volar surfaces of the ring and little fingers at their bases. Treatment consisted in excision of the burned tissue and closure by local pedicle flaps. Sensory examination revealed absence of pinprick and of two-point discrimination on the ulnar side of both the ring and little fingers. The ninhydrin prints (Fig. 10-B) showed scanty sweating in these regions but, nevertheless, some dots were present. On this basis, we thought that normal sensation might well return. Three months later, two-point discrimination was thirteen and eleven millimeters on the involved fingers; one year later, it was four millimeters.

As mentioned previously, considerable care and attention are necessary to obtain prints that are clear and represent the true function of the sweat glands in

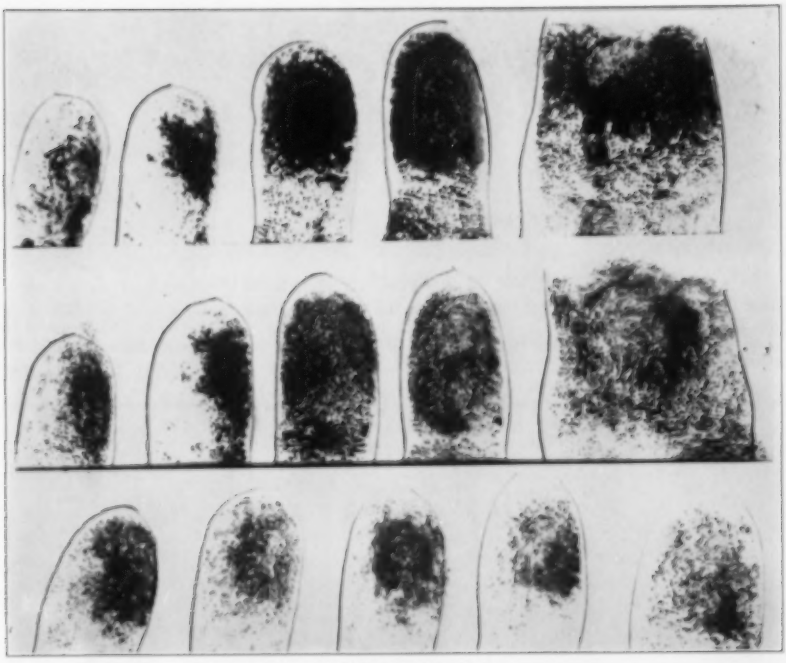

FIG. 10-B

Ninhydrin prints. The upper print was made at the time of excision of the burned tissue, the middle print was made three months later, and the lower print was made one year after operation. The ulnar sides of the little and ring fingers show diminished sudomotor activity in the upper and middle prints, but normal sweating in the lower print.

FIG. 10-C

Ninhydrin print made without removing excess sweat from the finger tips. The smudge makes the little-finger print useless for interpretation.

the finger tips. Moberg stressed this in a personal communication and maintained that the prints cannot be used to interpret sensory function unless discrete dots are obtained. It is not difficult to obtain ninhydrin stains of the finger tips that appear as a smudge or even as a conventional fingerprint with the rugae outlined. It is not possible, however, to obtain clear and distinct dots in every fingerprint made, as is shown in many of the examples. In Figures 10-C and 11, the problem of smudging is shown. During this study it became increasingly clear that the finger tips must be cleaned in order to obtain clear prints. Many patients are nervous during examination, and their hands become very moist. Sometimes, even though the finger tips were washed and then wiped dry, they were again grossly covered by sweat by the time a print could be made. This problem arose

FIG. 11

Ninhydrin print of a patient who had both digital nerves to the index finger sutured one month before. The staining shown on the index finger is due entirely to contamination. The print of the little finger is also too heavy for interpretation of the presence or absence of normal sudomotor function.

FIG. 12

Three ninhydrin prints of the same finger. The print on the left was made first, without preparation of the finger. This patient had dry finger tips. The print is light, and the sweat-gland orifices are not distinct. The middle print was made after the patient washed his hand with soap and water for ten minutes and dried the hand thoroughly. The print is more distinct. The print on the right was made after cleaning the finger tip with alcohol. The sweat-gland orifices are distinct and discrete.

in the patient whose prints are shown in Figures 10-A, 10-B, and 10-C. Many prints were made during the postoperative visits, of which only a few were of value for interpretation.

During the period immediately after injury, smudging due to excessive sweating was not a problem. Clear prints were usually obtained but, occasionally, the finger tips were so dry that almost no printing at all occurred. As one would expect, premedication with atropine reduced insensible perspiration to such a degree that few, if any, dots appeared.

No attempt was made to induce sweating by warming the patient by hot fluids or by medication. The only step taken before printing was to wash the hand in soap and water and, sometimes, alcohol. Figure 12 shows that careful cleaning of the finger tips will produce distinct dots that represent the sweat-gland orifices. Such preparations require time and reduce the acceptance of the ninhydrin test as a routine clinical procedure.

One explanation of the difference when our results are compared with those of Moberg might well be that our prints were not uniformly clear and distinct. Nevertheless, we find it difficult to believe that evidence of sudomotor function signified the return of any special sensation. In Figure 12 distinct dots are distributed over the finger tip, even though the radial digital nerve had been sutured only six weeks before. Neither pinprick nor two-point discrimination was present on the radial side of the finger.

SUMMARY

In considering the results of suture of the median and ulnar nerves, we have excluded cases in which nerve regeneration might be hindered by excessive scar, by tension at the line of suture, by long delay at carrying out operation, or by multiple operative procedures. We have attempted to correlate return of useful sensation in the hand with return of pinprick, two-point discrimination, and sudomotor function. One hundred and fifty patients were examined, thirty of whom were re-examined five or more years after operation. The ninhydrin prints appeared normal in twenty-four and obviously abnormal in only six of the thirty patients. Three had normal two-point discrimination. In twelve patients, Moberg's picking-up test was performed, and function was good or almost normal in only four.

Special attention was paid to the ninhydrin fingerprint test and to the picking-up test in the hope that an objective evaluation of the quality of sensory return might be possible. Both in patients with fresh injuries and in patients first seen weeks or months after nerve division who had not had nerve suture, anhydrosis was demonstrated with but a few exceptions.

Sweating and response to pinprick invariably returned together, and we have not found that the ninhydrin test is more specific than the return of response to pinprick as an indication of satisfactory sensory return. There was poor correlation between sweating and normal tactile gnosis. There was little correlation also between the return of either two-point sensation or tactile gnosis and the patient's ability to return to his former status in industry or in recreation.

The twelve children in this study obtained the best functional results. Two were followed for over five years and obtained nearly perfect return of function. Three children re-examined two years after operation had regained normal sensation and normal sweating. Two other children had normal sensation as early as thirteen months after nerve repair. These five children had normal sensation to pinprick, tactile gnosis, normal muscle function, and complete return of sweating. The remaining five children had been followed for less than one year and none of them had complete return of sensation or sweating at the time of follow-up.

CONCLUSIONS

Return of normal or almost normal sensation to the hand after median-nerve and ulnar-nerve suture requires at least five years in the adult and one to two years in children.

We are indebted to Moberg for stressing the fact that return of normal sensation is not necessarily indicated by the presence of perception of pinprick, light touch, or temperature change. It is best shown by recovery of normal two-point discrimination and by return of tactile gnosis.

Return of completely normal sensation is far less frequent than is commonly suspected in repair of the median and ulnar nerves.

The ninhydrin printing test is of value in the diagnosis of nerve injury, whether the division is complete or incomplete or whether the patient is seen early or late. It is of particular assistance in nerve injury because it is objective.

As a method of estimating return of function after nerve suture, certain limitations of the ninhydrin test are apparent. Although the ninhydrin prints improve in quality with improvement in sensation, increasing clearness in the prints is not always indicative of improved sensation. An accurate interpretation of these results is questionable.

Moberg's picking-up test is a good indication of the return of precision sensation (tactile gnosis) in cases of nerve injury involving the median-nerve sensory distribution.

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The Surgery of Gout in the Upper Extremity*

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Despite a better understanding of the manifestations of gout and their control, tophaceous gout, with its crippling deformities, is still seen. Although, in most instances, these deformities can now be prevented or improved by modern medical management, in some cases surgical intervention still proves a valuable adjuvant. In the past, the progressive development of most tophi could not be controlled effectively. With the introduction of benemid and other uricosuric agents, it appeared possible to produce urate resorption and to permit replacement by more normal tissues. In fact, the effectiveness of benemid has led Gutman and Yü to conclude that it is no longer necessary to resort to surgery for resolution of large tophi: they rely entirely on medical control [6]. Others [13], however, approve of more rapid correction, which seems a more realistic approach because of the avascular nature of tophi and the long interval required for resorption of an extensive lesion. Furthermore, our experience indicates that not all patients at present can be adequately controlled by medical therapy. Kammerer believes that about 5 per cent of the patients with gout fall into this category [9]. It is in this uncontrolled group in whom the severe manifestations of tophaceous gout still develop that surgical assistance is most justified. It is, therefore, important that the role of surgery in the control of tophaceous gout be more clearly defined. For this purpose we have analyzed our surgical experience in twenty-one patients in whom the upper extremity was involved with tophaceous gout. Our results in these patients suggest that, when function has been impaired or drainage and infection are present, surgery offers definite benefits.

HISTORY

The voluminous writings on the medical aspects of gout date back to 350 B.C., the time of Hippocrates. He, in one of the first reports on the surgical treatment of gout, provided relief from severe pain by burning the painful tophi with crude flax [1]. This treatment was later employed by Hermann Buschoff during the seventeenth century [8]. Paré relieved pain about tophaceous joints by using cautery after opening them and rubbing them with hermodactyl (colchicine), gentian, mercury, or alum. Hutchinson, in 1880, was the first to report on amputation for suppuration of tophaceous deposits. Riedel, in 1904, excised urate deposits from the metatarsophalangeal joint of the great toe on two occasions with good results. Lindsay wrote of his experiences in 1913 and commented on surgical techniques applicable to this problem [12]. Thomson, in 1920, reported on the local removal of gouty deposits [24]. Only these few scattered reports of surgical treatment were available until the authoritative report of Linton and Talbott in 1943 [13]. They based their conclusions on the excision of forty-one tophi from the lower extremity and forty-nine from the upper extremity in treating eleven patients with tophaceous gout. They also reviewed the records of the Massa-

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Miami Beach, Florida, January 7, 1961.

chusetts General Hospital and found only seven cases of gout for which operation was done during the previous 100 years. In 1958, Larmon and Kurtz reported the results of ninety-nine surgical procedures done over a ten-year period on twenty-three patients. Fifty-two of these procedures were on the lower extremity and forty-six were on the upper. The majority of the operations on the upper extremity were excisions with curettage, but, in addition, they reported six joint resections, three carpal-tunnel decompressions, and one amputation. Woughter recently reported a case in which resection of a tophaceous digit and ray transposition resulted in marked improvement.

The present report is based on the findings in twenty-one patients operated on over the past eighteen years at the Hospital for Special Surgery, the New York Hospital, and the Veterans Administration Hospital (Bronx), New York. All of these patients required surgery for tophi of the upper extremity; but, in addition, all had undergone surgery for gouty involvement of the lower extremity. Sixty-seven tophaceous deposits were removed from the upper extremities during thirty-six operative procedures in twenty-one patients.

GENERAL CONSIDERATIONS

Gout sufferers are widely distributed throughout the world, with an estimated number in the United States alone of 480,000 [21]. Of this number, approximately 10 per cent have tophaceous gout. It was originally believed that the etiology of gout was related to high living and too much alcohol, but this has been disproved. It is now generally recognized that the disease is the result of an inborn error of metabolism which permits an abnormally high production of uric acid. Careful studies have demonstrated a high familial incidence; the majority of sufferers (95 per cent) are men [22]. The fact that gout attacks men almost exclusively appears to be related to the manner of hereditary transmission and not to a sex-linked character[7].

Although the pathogenesis of gout is still unknown, the defect apparently lies in the conversion of glycine to uric acid. Whereas the normal pathway of degradation of glycine to uric acid is through adenine and other purine substances to nucleic acid and eventually to uric acid, in the patient with gout a more direct pathway is present which results in a persistent and abnormally large quantity of uric acid in the body. The quantity of circulating uric acid in the body has been termed the *miscible pool*. Studies by Benedict and associates, Geren and associates, and Bishop and associates would suggest that for the normal individual, the size of the miscible pool ranges between 700 and 1,300 milligrams and the turnover rate varies between 50 and 96 per cent of the miscible pool per day. In patients with gout, however, the pool size is usually double or more than double that of the normal, and the turnover rate considerably less. The urates in the deposits of the patient with tophaceous gout are almost completely isolated from the circulating uric acid. There is only limited interchange between the urates on the periphery of the tophi and those in solution in body fluids immediately adjacent. The low solubility of the urates in body fluids is responsible for their predisposition to precipitate in the bones and soft tissues in the person with gout.

In gouty arthritis, the characteristic lesions are deposits of monosodium urate-monohydrate in articular and periarticular structures. These deposits are most marked in the peripheral joints of the extremities—the smaller bones and joints of the hands and feet. In larger joints, the osseous changes are less severe or absent, and, although the tophi may continue to enlarge, they seldom produce marked restriction of function. Microscopic sections in early gout show these deposits

FIG. 1

Case F.H. Arteriosclerosis in a seventy-three-year old man with advanced gout. This may or may not be related to the disease process. (December 19, 1959.)

of urate to be in the upper layer of the articular cartilage [23]. This suggests, perhaps, that the urates migrate from synovial fluids rather than from the capillaries in the adjacent soft tissue or osseous structures [15]. Once this process has started in a joint, there appears to be an increased tendency for urates to precipitate in subcutaneous spaces adjacent to the joint. Soft tissues at a distance from these more vulnerable structures are rarely involved, except for the kidneys [20]. Tophi are conspicuously absent from muscle, liver, spleen, lungs, and nerve tissue. Their predilection appears to be not for the vascular but rather for the more avascular tissues, such as cartilage, epiphyseal bone, synovial membrane, bursae, ligaments, and tendons [25]. It is the involvement of these structures which is normally responsible for articular complaints.

On microscopic examination of articular cartilage, it has been noted that, with the infiltration of urates, cartilage cells lose their normal appearance. As the process progresses from the more superficial layers to the deeper layers, the cartilage is replaced by urate. Varying degrees of progression from area to area in a joint result in clefts and irregularities. The cartilage may be fibrillated and the lacunae filled with large numbers of cells. Some portions of the diseased cartilage may be covered by a fibrous pannus which arises from the synovial membrane [18]. At its junction with the articular cartilage, this proliferating synovial membrane often appears to be undermining and destroying the cartilage. In location and appearance, the pannus in gout does not differ from that seen in rheumatoid arthritis, but in gout urate deposits are present. In advanced gout, there may be loss of cartilage, replacement of cartilage by pannus, and eventually, manifestations of degenerative arthritis.

Periarticular tophi seem to develop only after there is joint involvement [22]. They are usually lobular and contain urate crystals interwoven with fibroblasts, polymorphonuclear cells, lymphocytes, plasma cells, and foreign-body giant cells.

FIG. 2

This lesion shows skin invasion by tophaceous material.

The degree of cellular inflammatory reaction in a given tophus is a variable feature. As the tophus enlarges, the adjacent soft tissues become compressed; it is this compressed connective tissue which appears to be a capsule surrounding the enlarging tophus.

Urate deposits are found in bone and are more commonly seen in the juxta-articular region than in the shaft. When resorption of these deposits accompanies uricosuric administration, bone replacement of the defect may occur.

Tendons are frequently involved in tophaceous gout. These lesions may be discrete fusiform or nodular enlargements of tendons or part of a massive infiltration. Nerve and muscle compression have been noted in some instances, but in no instance has actual invasion been reported. It is only in areas where a tophus can produce increased pressure on a nerve, as in the carpal tunnel, that compression has been reported. The urate crystals themselves do not invade blood vessels, although they may surround them or alter their course by displacement. While previous reports have suggested that the peripheral circulation is altered in gout, this may be a local phenomenon (Fig. 1).

Linton and Talbott emphasized that, except for primary dermatitis, the skin is rarely involved by gout [13]. Our experience suggests that there is frequent urate infiltration of the skin directly overlying a superficial tophus. Disastrous results have been reported when the thin attenuated skin overlying a large subcutaneous tophus is elevated as a flap. This is probably related to the nutritional changes produced by an expanding lesion and the deposits of urate within the skin itself (Fig. 2).

DIAGNOSTIC FACTORS IN GOUT

The diagnosis of gout is classically established on the basis of history, physical examination, laboratory studies, and roentgenographic findings. The history is one of intermittent acute attacks of arthritis with periods of remission. The concentration of the serum uric acid in patients with gout is usually above six milligrams per 100 milliliters, whereas in normal persons it is below this level. The level is not altered by the phase of the disease. The characteristic roentgenographic findings in gouty arthritis include circular, or punched-out, juxta-articular areas

FIG. 3-A

Case L.C. Roentgenogram made on August 7, 1951. Note the "punched out" juxta-articular lesions.

FIG. 3-B

Right hand. Preoperative photo shows extensive tophaceous involvement at the second and third metacarpophalangeal joints. This is a site frequently affected.

of rarefaction, diminution of the joint space, and adjacent soft-tissue swelling [14,18] (Figs. 3-A and 3-B).

On this basis, some authorities state that it is relatively easy to establish the diagnosis. It was surprising, therefore, to find in this series of patients that, although, in many instances, the diagnosis was established immediately at the onset

of symptoms, in some patients, delays of up to ten years occurred before the diagnosis of gout was established. This was usually related to the atypical early manifestations of the disease. It is well known, for example, that the passage of renal stones, elevation of blood pressure, and albuminuria may precede the initial articular symptoms. Three of our twenty-one patients passed renal stones and urinary gravel five, ten, and fifteen years before they had any joint symptoms. Another patient experienced gross hematuria at the time of her initial attack as a result of a high urinary concentration of urate crystals. In many patients in this series, unexplained slight blood-pressure elevation and minimum albuminuria were recorded well in advance of the initial attack of arthritis.

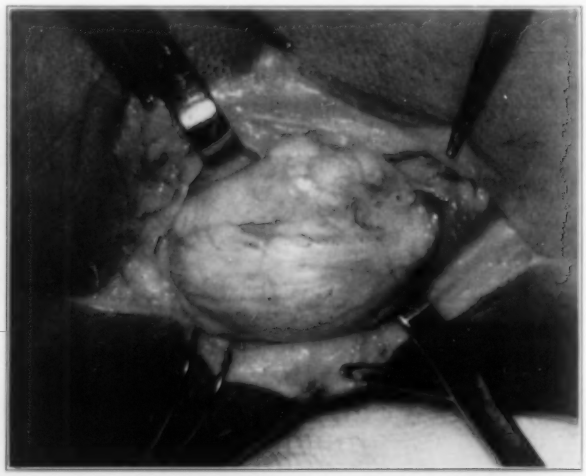

FIG. 4-A

H.S., Case 2. Tophaceous mass in flexor digitorum sublimis superficialis of the long finger, proximal to the transverse carpal ligament preventing finger extension.

FIG. 4-B

December 9, 1960, four years after operation. There has been no recurrence of tophi in the flexor tendons. The large tophi in the fingers remain despite careful and controlled therapy.

When the initial joint symptoms did not involve the great toe but involved instead the knees, ankles, hands, wrists, or elbows with either monoarticular or polyarticular localizations, the diagnosis of rheumatoid arthritis was sometimes initially favored over that of gout. Since 10 to 20 per cent of patients with rheumatoid arthritis have elevated serum urate levels, this test may not aid in the differential diagnosis [22]. If such a patient suffering from gout is erroneously presumed to have rheumatoid arthritis and is treated with salicylates, the uricosuric properties of the drug may effect a rapid response. This appears to lend credence to the diagnosis of arthritis. It is often only at a later date when the disease process has progressed to the tophaceous state, or when roentgenographic changes occur, that the correct diagnosis is established.

In the differential diagnosis of a single, inflamed, swollen joint, it is occasionally necessary to rule out the possibility of joint sepsis. Although a temperature elevation and leukocytosis suggest sepsis, a history of recurrent arthritis, the absence of ascending lymphangitis, roentgenographic findings compatible with gout, and a response to colchicine therapy may be helpful in making the differential diagnosis. Since fulminating sepsis involving a tophaceous joint is rare, immediate surgery is seldom indicated.

The relative diagnostic value of the serum uric acid deserves consideration. Although colchicine has no effect on serum uric acid levels or the excretion of urates by the kidney, it should be recalled that salicylates, steroids, probenecid, and phenylbutazone do have an effect and should not be administered during the forty-eight-hour period before a serum uric acid test. The serum uric acid may be elevated in several conditions not usually associated with clinical gout. These include renal insufficiency, in which hyperuricemia may be secondary to diminished urinary excretion; myelofibrosis, leukemia, and polycythemia vera, in which an increased cell breakdown yields greater amounts of uric acid; and idiopathic hyperuricemia. Patients with these conditions have no familial history or clinical evidence of gout [22].

The factors which most frequently incite an attack of acute gouty arthritis are trauma, drugs, acute infections, blood loss, prolonged bedrest, and surgical operations. A high purine diet and alcoholic beverages may also precipitate attacks in the hypersensitive person with a severe gouty diathesis; but, in many cases, they bear little relation to either the frequency of acute attacks or progression of the disease process. A direct blow or the chronic irritation of ill-fitting shoes or gloves appears, in some instances, to precipitate an acute attack of gouty arthritis. Also such drugs as penicillin, thiamine chloride, vitamin B_{12}, insulin, ergotamine tartrate, and, more recently, chlorothiazide have been implicated as inciting agents [27]. Acute infections—pharyngitis, sinusitis, furunculosis, or even an infected draining tophus—are frequently associated with the onset of gouty episodes.

ANALYSIS OF CASES

Nineteen of the twenty-one patients in this series were men. Their average age at the time of the initial attack of gout was thirty-six years. Gout is considered to be rare before puberty; in the men in our series the earliest recorded attack was at the age of sixteen. The onset of acute articular symptoms in the two women occurred at eleven and fourteen years of age. This is surprising since, in women, gout is usually seen after the menopause. Only three of our patients had a known family history of gout.

Despite the fact that, in many patients in the present series initial articular symptoms did not involve the great toe, in 76 per cent of the patients the great toe was the site of primary tophus formation. In two patients, the ear was a primary

site. The first tophus was found on an average of nine years after the onset of acute articular symptoms. In no patient did the initial tophus appear on the upper extremity. Apparently, the upper extremity becomes involved only in severe forms of the disease, since all of our patients had extensive tophaceous gout elsewhere. When deposits did occur in the arm or hand, the most frequent initial sites were the elbows and interphalangeal joints of the fingers. In this series the primary sites in the upper extremity were the elbow in seven, the proximal interphalangeal joint in seven, the second metacarpophalangeal joint in six, and the distal interphalangeal joint in one. Later deposits were also usually in areas subjected to frequent pressure or irritation and at points of skin tension. Although the relation of these factors to the predilection of the disease process for certain sites is as yet unclear, there appears to be some positive correlation. It is of interest that in one patient, a finger injury, which preceded the onset of gout, destroyed all active and passive motion in that finger. At a later date when all the other fingers and toes had become extensively infiltrated by tophaceous deposits, this finger, curiously enough, was completely spared.

In our patients no visible tophaceous deposits occurred about the shoulder, although many patients had attacks of acute gouty arthritis in this joint. Roentgenographic changes consistent with osteo-arthritis were often reported, but in none were the classic roentgenographic features of gout present.

Tophaceous deposits were surgically removed from the elbow region in sixteen patients. All deposits were on the extensor surface; they usually overlay the olecranon or the proximal end of the ulna, but in several instances they were present over the epicondyles of the humerus. These deposits were located in the subcutaneous tissue, but were frequently attached to the underlying bone, the tendinous insertion of the triceps, or the origin of the extensor carpi ulnaris. Superficially, the overlying skin was often involved. The tophi in the elbow region were usually encapsulated and found to contain either semisolid or solid deposits.

In one patient many small, discrete tophaceous deposits were found over the extensor surface of the forearm from the elbow to the wrist. In many patients a small tophaceous deposit was noted over the ulnar styloid process, but in no patient was excision considered necessary.

Tophi over the dorsum of the hand, usually adjacent to the metacarpophalangeal joints, were excised in seven patients. In contrast to those in the region of the elbow, these tophi were found to involve, diffusely, skin, subcutaneous tissue, tendons, ligaments, joints and their capsules, and bone. The tophi also surrounded nerves and blood vessels, but did not appear to directly invade them. Similar involvement was found in the thirty-five tophi removed from the dorsal or volar surface of the fingers. However, on the volar surface, the flexor-tendon sheath appeared to limit the extension of the tophus. Although the sheath was usually surrounded by urate deposits, in no instance were the flexor tendons within the sheath invaded.

The pads on the volar surface of the finger tips were sometimes replaced by urate deposits. As these deposits increased in size, tenderness frequently limited use of the finger and drainage was not uncommon. In four patients tophi were removed from the finger pads; at operation the tophi were found to involve not only skin and subcutaneous tissue but also the adjacent bone of the distal phalanx.

Of great interest were four patients (one with bilateral involvement) in whom, at operation, urate deposits at the wrist level were found to involve the flexor tendons of the fingers. In one wrist, both sublimis and profundus tendons were in-

filtrated; in the remaining four, only the sublimis tendon was involved. The tophi were diffusely infiltrated among the tendon fibers, but always encapsulated and confined to the tendon substance. In some of the patients extensive involvement destroyed the tendon continuity, but in no patient did actual tendon rupture occur. The deposits were located beneath the fascia and did not directly involve skin, subcutaneous tissue, adjacent nerves, or blood vessels. In one hand, the tophaceous mass produced compression of the median nerve; in the other four, it resulted in flexion contractures in the fingers.

CASE 1. C.A. experienced the first symptoms of gouty arthritis at the age of fourteen. By the time she was twenty-seven, she had tophaceous enlargements of some of her fingers and toes, and progressive enlargement of the tophi in her fingers greatly impaired motion. For these reasons and because of drainage from several tophaceous sites, surgical excision and curettage of tophi of both upper and lower extremities were performed on February 9, 1946, with good results.

In September 1946, the patient began to complain of numbness and tingling in the thumb, index and long fingers of her right hand. A large round mass was noted on the volar surface of the right wrist which measured 6.5 by two centimeters. This mass did not involve skin or subcutaneous tissue and seemed to lie deep to them. There appeared to be no limitation of finger flexion or extension which could not be explained on the basis of intrinsic digital disease.

On September 28, 1946, under general anesthesia and with the use of a pneumatic tourniquet, the volar surface of the left wrist was explored through a transverse incision. Beneath the deep fascia, a large mass measuring four by two centimeters was found to involve all of the flexor digitorum sublimis tendons at the wrist level. This mass lay in close proximity to the median nerve and appeared to compress it against the anterior aspect of the radius. Since there was no involvement of the underlying flexor digitorum profundus tendons, the mass was completely excised. Some increased ease of finger extension was noted immediately following excision. On section, the mass was completely made up of white crystalline material and at no point could a true tendinous structure be identified.

During a seven-year follow-up, complete return of sensory function of the median nerve was noted. There was no evidence of further deposition of urates at the wrist level from the time of surgery until the patient died of uremia at the age of forty-three.

CASE 2. H.S., a fifty-year-old store manager, first had symptoms of acute gouty arthritis in both ankles at the age of twenty-nine. Despite recurrent attacks, it was three years before a definite diagnosis of gout was established. At the age of thirty-four, he first began to note pain in his hands; later, multiple tophaceous deposits developed on all fingers.

At forty-three years of age, he experienced a snapping sensation in his right wrist when he flexed his long finger. Shortly thereafter, this finger became locked permanently in almost complete flexion and remained so for the ensuing two-year period. On examination, the right long finger was found to be flexed into the palm and fixed in this position. Over the volar surface of this wrist, a large mass was seen just proximal to the flexion crease. On attempted extension of the long finger, the mass moved slightly. On August 21, 1956, under general anesthesia and with the use of a pneumatic tourniquet, the right wrist was explored through a curved incision over the volar carpal ligament. A large tophus, measuring 5.3 by two centimeters, was identified within the substance of the flexor digitorum sublimis tendon of the long finger. This tophaceous deposit lay entirely proximal to the transverse carpal ligament (Figs. 4-A and 4-B).

The size of the deposit prevented the sublimis tendon from passing beneath the ligament when extension of the long finger was attempted. No other tendons were involved by the encapsulated tophus, and the profundus tendon to the long finger was intact and functioning. For this reason, the entire tophus and the involved portion of the sublimis tendon were removed. No attempt was made to re-establish continuity. The median nerve showed no evidence of compression, and the other remaining structures appeared quite normal. The patient had an uneventful postoperative course, and in the fourteen-year period since surgery he has maintained a full range of active extension and flexion in the long finger.

CASE 3. D.C., a mystery-story writer, fifty-eight years old, first had symptoms of gouty arthritis at the age of thirty-eight. Initial symptoms were a swollen, warm, and painful right wrist. Later involvement included hands, wrists, and feet. There was a family history of gout. Progression of the disease and tophus formation ensued despite attempts to control the disease with every known uricosuric agent. Colchicine in this patient was reliably reported to have aggravated the disease process. In 1957, hemolytic anemia was confirmed by bone-marrow studies.

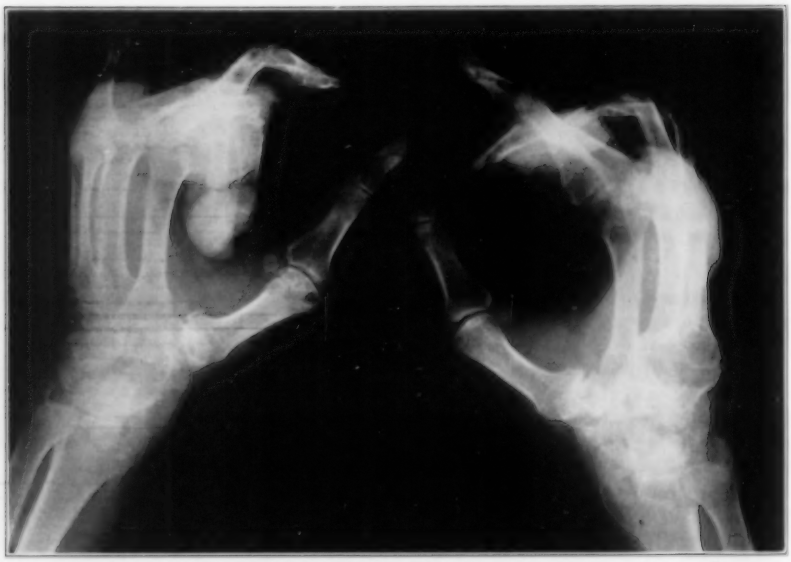

FIG. 5-A

D.C., Case 3. Roentgenogram made on December 9, 1957. Note flexion deformities of the long and ring fingers of the left hand. Fixed flexion of the index and little fingers developed subsequently.

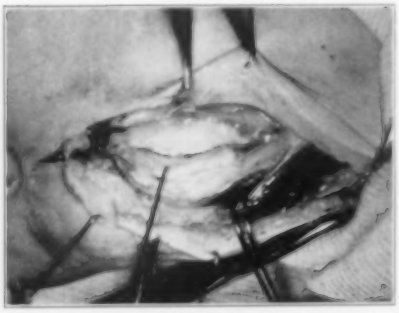

FIG. 5-B

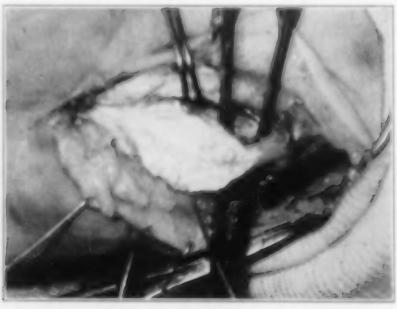

FIG. 5-C

Fig. 5-B: Tophi in both sublimis and profundus tendons.

Fig. 5-C: Evacuation of tophus in profundus tendon.

Fig. 5-D: Closure of produndus tendon.

FIG. 5-D

In December 1956, after an acute attack of gout, the long and ring fingers of the right hand were locked in almost complete flexion; in addition, there were mild flexion deformities in the right little finger and in the left long, ring, and little fingers, accompanied by tophi over the metacarpophalangeal and proximal interphalangeal joints of these fingers (Fig. 5-A).

On December 10, 1957, under general anesthesia and with the use of a pneumatic tourniquet, the right wrist was explored through a transverse incision. A fusiform swelling, four centimeters in length, involved the sublimis tendons of the long and ring fingers. The epitenon of these tendons enclosed the mass which was in close approximation to the ulnar and median nerves but did not

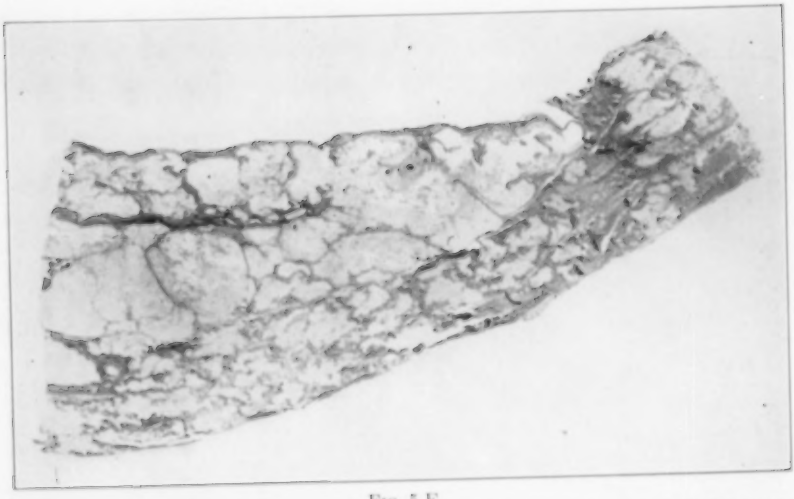

FIG. 5-E
Invasion of tendon by tophaceous material. Note the encapsulation of the tophus by the epitenon.

FIG. 5-F
December 1960. There is some improvement in function despite continued severe advancement of disease in his hands. There is now a mass in the flexor digitorum profundus of the index finger at the mid-palmar level.

involve them. Once the mass was resected, it was possible to extend the long and ring fingers passively. There was no involvement of adjacent structures. The patient had an uneventful postoperative course. Although further tophaceous changes on the digits themselves limited finger motion, there was no evidence of recurrent tophus formation at the wrist level.

When re-examined on May 18, 1959, the patient had excellent function in the right hand, which had been operated on. In the left hand, however, he had similar locking in the long and ring fingers, and to a lesser degree, in the index finger. One month later, the index and little fingers were also completely locked in flexion. As a result all fingers, except the thumb, were held in marked flexion.

On June 23, 1959, under regional block anesthesia and with the use of a pneumatic tourniquet, the left wrist was explored through a curved incision. Just proximal to the transverse carpal liga-

FIG. 6-A

E.R., Case 4. Preoperative photograph of the long finger locked in flexion. Note the mass on the volar surface of the wrist proximal to the transverse carpal ligament.

ment, a marked thickening of the sublimis tendon of the index finger was found. This segment of tendon, containing a tophus, measuring 2.5 by four centimeters, was excised. The tophus appeared to arise directly within the center of the tendon; and although tendon fibers were distorted and destroyed at this level, the surrounding epitenon was still intact. The transverse carpal ligament was then opened throughout its full length and a portion of the ligament was excised. The median nerve showed evidence of compression. The underlying profundus tendons were found to have tophaceous enlargements just proximal to the carpal-tunnel level. Because resection of these tendons was not feasible, diamond-shaped blocks were resected from each enlarged area and the defect so formed closed by suture of the surrounding epitenon (Figs. 5-B, 5-C, 5-D, and 5-E).

Since this procedure was performed under regional block anesthesia, the patient was able to move his fingers on command throughout the procedure. At the completion of surgery, he was able to extend his fingers from their original position of about 60 degrees of fixed flexion at the metacarpophalangeal and proximal interphalangeal joints out to 150 degrees. Over an eighteen-month period after surgery, the improvement was maintained; and, although tophaceous material was left behind in the profundus tendons, there was no clinical evidence that further tophaceous accumulations had been precipitated at this site (Fig. 5-F).

CASE 4. E.R., a male dental technician, thirty-four years old, experienced his first attack of acute gouty arthritis at the age of nineteen. There was no family history of gout. When he was thirty, although no tophi were noted, renal studies demonstrated poor concentration, diminished phenolsulphonphthalein excretion, and, on retrograde pyelography, a small right kidney.

At thirty-four, pain and a swelling over the flexor surface of the right wrist and a flexion contracture in the long finger developed.

Over a two-month period during which cortisone and phenylbutazone were administered, the patient failed to note improvement and hospitalization was advised.

On physical examination, the right long finger was flexed into the palm and fixed in this position. On the volar surface of the right wrist was a three-by-two-centimeter mass which was tender and moved slightly with attempted extension of the long finger (Fig. 6-A). Tophi were noted on both ears and both hands, over the left olecranon, over both Achilles tendons, and over the right first metatarsophalangeal joint. The serum uric acid was 16.1 milligrams per 100 milliliters and the blood urea nitrogen, 72 milligrams per 100 milliliters.

Initially, relief of acute symptoms was obtained by the ingestion of colchicine to the point of toxicity. The patient was then placed on a low purine diet, colchicine, 0.65 milligrams, twice a day,

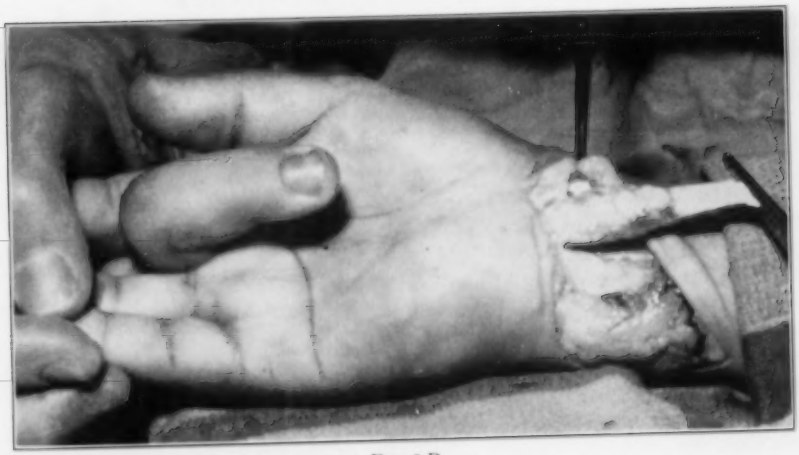

FIG. 6-B
Excision of the tendon to the tophus, April 8, 1960.

FIG. 6-C
Postoperative photograph showing release of the flexor mechanism after removal of tophaceous block.

and benemid, three grams a day. Fluids were forced and ten grams of sodium bicarbonate was administered daily to maintain an alkaline urine. This therapy over a four-month period failed to reduce the frequency of attacks or the size of the tophi.

The marked flexion contracture of the right long finger persisted, and the mass on the volar surface of the right wrist showed no obvious change in size although the acute symptoms had subsided. On April 8, 1960, under general anesthesia and with the use of a pneumatic tourniquet, the flexor surface of the right wrist was explored. Through an L-shaped incision, a fusiform swelling of the flexor digitorum sublimis tendon of the long finger was found just proximal to the volar carpal ligament. This encapsulated, tophaceous deposit, because of its size, would not pass beneath the carpal ligament. The involved portion of the tendon was therefore excised (Fig. 6-B). Continu-

ity was not re-established since the corresponding profundus tendon was found to be intact and functioning normally (Fig. 6-C). No other deposits were noted. Eight months after operation, there was no evidence of further deposition of urates at the operative site. A normal range of motion was present in the right long finger, and the patient's gout was fairly well controlled at that time.

INDICATIONS FOR SURGERY

The indications for surgical intervention in the treatment of tophaceous gout suggested by Linton and Talbott have been extended by Larmon and Kurtz and by Woughter. These indications fall into four main categories: functional, symptomatic, cosmetic, and metabolic. We have grouped them as follows: (1) functional, which includes excision to permit wearing of clothing and gloves, restoration of motion, and stabilization of joints; (2) control of drainage and infection; (3) reduction of pain; (4) decompression of nerves; (5) cosmetic restoration; and (6) metabolic, that is, to lessen total body urate. Our experience indicates that in tophaceous gout of the lower extremity, surgical intervention is used mainly to permit the wearing of shoes, to stabilize joints, to relieve pain, and to control infection. By contrast, surgical procedures in the upper extremity are usually for the restoration of function, for the control of infection and drainage, and, in some instances, for cosmetic purposes. Surgery is rarely needed for the control of pain. It is of interest historically that nearly all procedures were performed for the relief of pain. The recent advances in the control of gout through the combined use of colchicine and the newer uricosuric agents permit the surgeon to direct his attention to the correction of functional and mechanical disabilities incurred by this disease. In this series fifty-four operations were performed on the upper extremity to improve function, six to treat drainage and infection, five to relieve pain, one to improve appearance, and one to relieve nerve compression.

The major indication for excision in fifty-four of sixty-seven tophi in this series was restoration of function. Tophi about the elbow and on the dorsum of the hand were removed when they prevented the patient from wearing clothing or were considered a physical hazard because of repeated trauma. Surgery was also done several times when a patient's occupation normally required the wearing of gloves which tophaceous involvement of fingers and hands prevented. Operative procedures were carried out in the wrist in five hands when tophaceous enlargement of flexor tendons limited normal excursion beneath the carpal ligament and prevented finger extension. In one patient median-nerve decompression was required for the relief of symptoms produced by a tophus.

Tophus formation at the level of the metacarpophalangeal joint in seven of the patients operated on limited extension and flexion not only through joint involvement but also through extensive infiltration of the extensor tendons and their hoods. This fixation of the extensor mechanism at the metacarpophalangeal joint often limited, in addition, the action of both the extrinsic and intrinsic extensor tendons on the interphalangeal joints. In some patients, flexion also was impaired at the proximal and distal interphalangeal joints by the tenodesis action of the fixed extensors. In several patients, fixation of the extensors caused intrinsic-plus deformities not unlike those seen in rheumatoid arthritis.

Tophaceous involvement in the fingers, both articular and periarticular, also produced limitation of finger motion, and when this involvement caused loss of balance between the extensor and flexor-tendon mechanisms, mallet-finger, boutonnière, and hyperextension deformities were produced.

In six patients, chronic drainage from a sinus was the primary indication for surgery. Chronic, draining sinuses should probably receive more attention than they have in the past, even though the absence of severe localized or systemic manifestations in the presence of a draining tophus has suggested that they are

FIG. 7-A

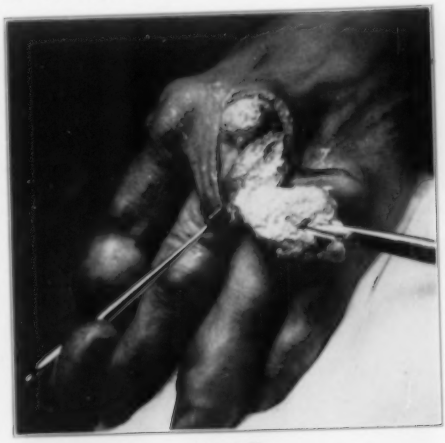

FIG. 7-B

FIG. 7-C

Fig. 7-A: Large tophi overlying the second and third metacarpophalangeal joints.
Fig. 7-B: Partial excision of the tophus. Note the preservation of the extensor tendon mechanism.
Fig. 7-C: The greater part of the tophus has been removed without any loss in the functional unit.

innocuous. Furthermore, tophaceous material is generally considered to be bacteriostatic. While urates may be a poor medium for the growth of bacteria, these chronic infections are sometimes a low-grade osteomyelitis and may result in extensive bone and joint destruction.

Surgical excision was performed just for cosmetic purposes in only one patient, although in many others improvement in appearance was a secondary consideration. Pain could nearly always be controlled by medication; pain was an indication for surgery only five times. In one patient severe pain, associated with marked destruction of bones and soft tissues of a finger, necessitated amputation. In four instances painful tophi on finger tips were improved with curettage.

Although it was not a primary consideration in this series, the decrease of the total amount of urates in the body was also an important factor in the decision to remove large tophi, particularly those about the elbow. A surgical procedure was considered in the majority of cases only when uricosuric agents, administered over a long period of time, had failed to decrease significantly the size of the tophi or to alter the indications for surgery.

PREOPERATIVE EVALUATION

Regardless of the apparent mildness or severity of the disease, patients with gout require a complete evaluation when surgery is contemplated. The kidneys should receive special consideration since their function is frequently impaired in this disease. Accurate testing is necessary because no relation exists between the severity of symptoms and the degree of renal damage [23]. Thirteen of twenty-one patients in this series had significant renal damage, as evidenced by an elevated blood urea nitrogen, diminished urine concentration, and phenolsulphonphthalein excretion. The passage of gravel was a common occurrence. Hematuria,

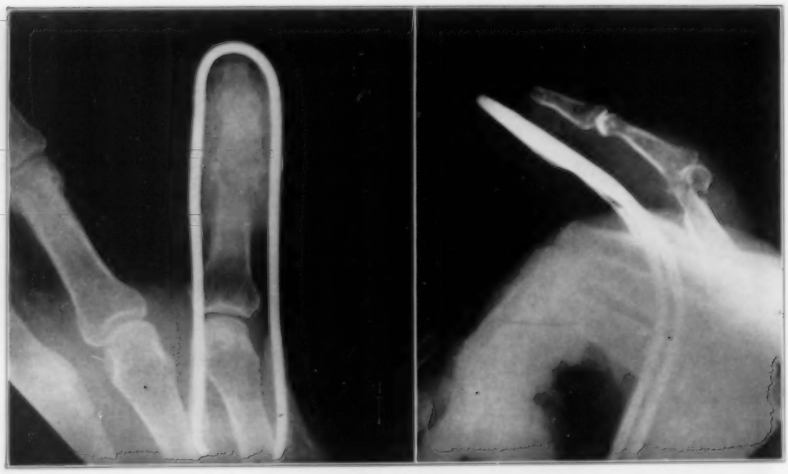

FIG. 8-A

Case F.H. Pathological fracture in a lytic lesion produced by gout: same patient as that shown in Fig. 1. This is a rare finding in gout. (April 19, 1950.)

FIG. 8-B

Case F.H. at age seventy, five years following fracture. Note the advanced articular destruction due to gout. (August 12, 1955.)

both gross and microscopic, was also a frequent finding. Two patients had bilateral staghorn calculi and another required surgical removal of a ureteral stone.

Evaluation of the patient's cardiovascular status is also important: eight of our twenty-one patients had hypertension. Blood disorders are also more frequent in patients with gout, and two of our patients had hemolytic anemia.

SURGICAL MANAGEMENT

General Considerations

The surgical management of gout is largely confined to the removal of tophi.

Encapsulated deposits around the olecranon may be totally excised just as any other form of encapsulated tumor. These discrete tophi are also occasionally seen adjacent to the metacarpophalangeal joint on the dorsum of the hand.

Large invasive tophi over the dorsum of the metacarpophalangeal joint, when uncomplicated by any skin opening, are best removed through a transverse approach. If the lesion is on the finger, resection may be carried out through a transverse or standard mid-lateral incision. In these cases a pneumatic tourniquet is preferred to aid in identification of normal structures proximal and distal to the lesion. They can then be followed into the mass with less chance of damage. It is particularly important to isolate digital nerves, extensor tendons, and lateral bands in this fashion. A digital nerve may be surrounded by urates, but it can be dissected free since the lesion will not penetrate the nerve. The fibers of the extensor hood and lateral bands, however, are often separated by infiltrated urates. It is neither practical nor necessary to remove all of the tophaceous material from these important structures. That which is closely adherent should be left in place or gently curetted or irrigated from the surface. It may be possible, as well, to curette away the material lying beneath these structures. No attempt should be made to remove the tophus completely if excision will permanently damage structures required for future function (Figs. 7-A, 7-B, and 7-C).

When the crystalline material has penetrated the subdermal layers in large, old tophi, it is impossible to remove all deposits without doing massive excision of skin. It is, therefore, advisable to neglect these skin deposits, doing no more than gentle curettage. After removal of a large central tophus, it may be necessary to compress the overlying infiltrated skin into the defect to minimize the dead space. It has not been necessary in the current series to do any skin-grafting.

When tophaceous deposits are found to extend into periosteum and bone and to replace them (Figs. 8-A and 8-B), a conservative curettage of these areas should be carried out in conjunction with soft-tissue excision. Every effort is made to preserve the remaining periosteum and shell of bone in order to maintain continuity of the skeletal architecture. In some instances, these areas are later replaced by bone. We have not considered it necessary to pack any cavities with bone chips, and the remaining dead space has not resulted in a serious postoperative complication.

Tophaceous material may occasionally be deposited in the flexor tendons. This finding was previously reported by Linton and Talbott. When large deposits involve one or more of the sublimis tendons and act as a block to function at the level of the transverse carpal ligament, local resection of the mass alone is not sufficient. With the profundus tendons intact, the entire involved segment of each sublimis tendon should be excised and discarded. When the profundus tendons are partially involved, it may be possible to curette out the tophaceous material in these and still preserve tendon continuity.

Carpal-tunnel syndrome may result with compression of the median nerve by uraceous deposits within the flexor tendons. This complication was previously reported by Ward [26].

Care of Open Tophaceous Lesions

Small superficial tophi may point and drain spontaneously. Patients report that they evacuate these tophi by gentle pressure; healing is usually prompt.

Chronic, draining sinuses are a problem in severe gout, and we believe that surgical intervention may be indicated. Although in most patients the infection seems to be low-grade, it is our experience that continuous drainage may eventually result in extensive bone and joint damage. An infected draining sinus may require

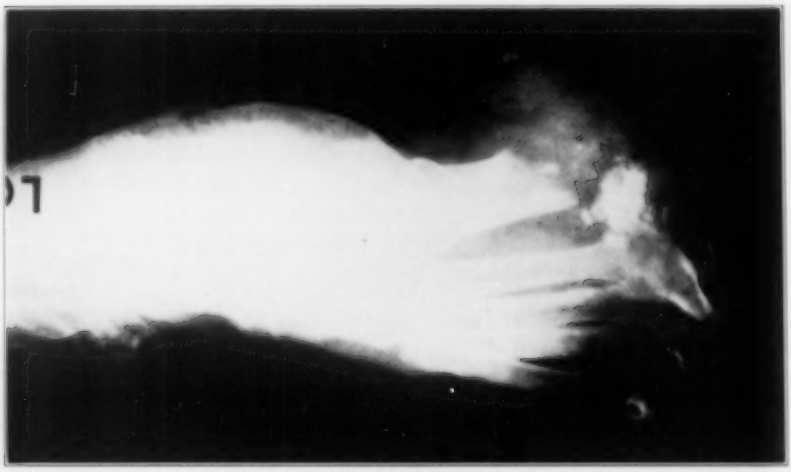

FIG. 9-A

Case L.C. Roentgenogram showing osseous destruction caused by tophaceous replacement and by infection.

FIG. 9-B

Massive tophus of foot with cellulitis. This was acting as a sequestrum. Healing occurred rapidly following its removal.

moist soaks and antibiotics prior to surgery. When the sinus appears relatively clean, it can be surgically enlarged and the underlying tophaceous material removed. Should it be encapsulated, total excision is possible. When, however, a draining lesion is located in the region of the dorsum of the hand or over a finger, it is more likely that only a partial removal of the tophaceous material can be accomplished. As much as possible of the urate deposit is curetted away, care being taken to preserve essential structures. This will permit a collapse of the overlying cutaneous layers and will provide a better opportunity for the sinus to heal. Such wounds should be left totally or partially open.

On rare occasions, very large tophi may act as foreign bodies and behave almost like bone sequestra in osteomyelitis (Figs. 9-A and 9-B). In one patient in

FIG. 10-A

Case B.K. Destructive tophaceous replacement in the hands of a fifty-one-year-old woman with gout of forty years' duration.

FIG. 10-B

Figs. 10-B and 10-C: Hand function has been improved by a program of surgical procedures and careful medical management.

whom a massive lesion was accompanied by acute cellulitis in the foot and leg, surgical amputation was contemplated at another hospital. We found that simple enlargement of the draining sinus allowed the sequestrum to be lifted out *en masse;* the wound was then packed open and responded with the prompt formation of granulation tissue and healing of the wound.

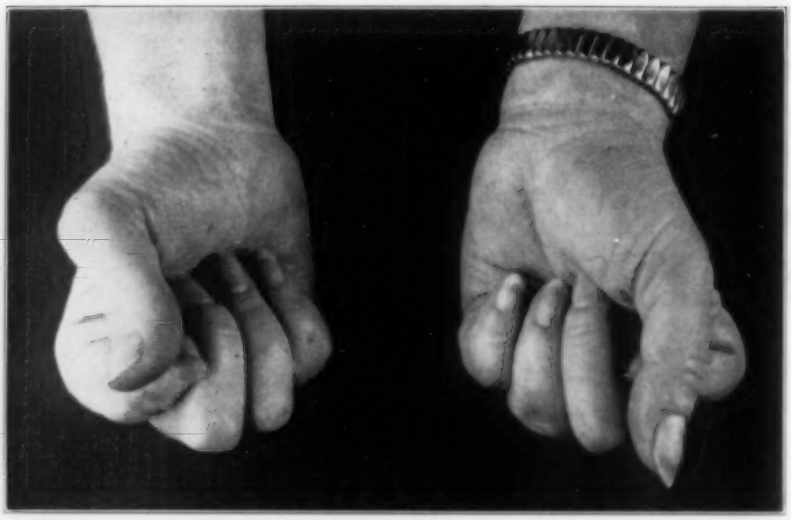

FIG. 10-C

Preservation of Function

Occasionally manifestations of gout may be similar to those of rheumatoid arthritis. The intrinsic-plus deformities that occur in the gouty hand appear to be secondary to intrinsic articular and periarticular tophi. Operative removal of tophi as just outlined may not suffice to correct these deformities. It will sometimes be necessary to supplement excision with intrinsic releases or freeing of the extensor hoods.

It should be rarely necessary to sacrifice a digit, even in the presence of severe pathological change. Only when persistent pain impairs finger function, uncontrolled drainage and infection are present, or enlargement of a digit hinders the function of those adjacent to it, should amputation be considered.

Although bones and joints may be replaced by urate deposits, their over-all architecture is usually preserved, and the deposits are sufficiently rigid to maintain essential skeletal support. In spite of extreme roentgenographic changes, a surprising degree of function may remain. Joints will usually remain stable and have little pain associated with motion. On rare occasions we have observed joints that have become completely unstable with extensive tophaceous infiltration. In these cases, joint fusion may be necessary in order to restore bone continuity and to improve function.

Not once in our treatment of the manifestations of gout in the upper extremity have we felt it necessary to resort to extraordinary measures in attempting to restore function. It would seem unwise in most patients to attempt such procedures as joint reconstruction and ray transfers because of the unpredictable nature of the disease process and, therefore, the uncertainty of the result.

POSTOPERATIVE COMPLICATIONS

It is well recognized that surgery of any kind can produce an acute attack of gouty arthritis, yet the mechanism of its production is not clearly understood. One possibility is that it is precipitated by the autodestruction of injured cells which elevate the body uric acid. Another is that these attacks are intimately related to systemic changes which accompany surgical procedures. Such acute attacks may occur at any time during the post-surgical period but are most frequent about the

second day. It is important that the surgeon anticipate this possibility and not confuse it with a local complication of surgery. When surgery is being contemplated in the known gouty patient, colchicine should be administered for at least two to three days preoperatively and postoperatively.

In the present series, an acute attack of gouty arthritis occurred during the immediate postoperative period after ten of thirty-six operative procedures. In all except one of the patients, adequate doses of colchicine were being administered at the time of the attack. In addition to colchicine, the majority of patients received some uricosuric agent. These attacks seem to be unrelated to the type of anesthesia employed.

Penicillin has been implicated as an agent that may produce acute attacks of gouty arthritis. In this study, an attempt was made to evaluate this effect. Eleven patients received penicillin during the postoperative period, and five of the eleven had an acute attack. Five acute attacks of gout were also recorded in the remaining ten patients who did not receive penicillin. It would appear that penicillin had little relation to the onset of the acute attack.

Wound healing after the surgical removal of tophaceous material is good. No major complication was encountered in any patient in the present series, even though surgery was employed to eradicate a draining sinus tract in six instances. In all except six patients, the wounds healed *per primam;* in these, there was drainage of urates, but these sinuses closed spontaneously one to four months after operation. Two minor infections were recorded in the postoperative wound which responded promptly to moist dressings and antibiotics. In many of our patients, the skin overlying the tophus was infiltrated with urates, but in no instance was excision of the involved skin carried out. The fact that no major losses of skin were recorded suggests that skin-grafting is seldom necessary.

The very nature of this disease prevents accurate long-term evaluation. In only three instances has a tophus recurred; one of these was larger than that originally removed. The remainder of the patients have shown lasting improvement. Excisions of tophi about the elbow have proved most effective. In those patients with flexor-tendon involvement, which was treated by excision of the tendon or the tophi, or both, improvement in function persisted during the follow-up period of from six months to sixteen years.

Three patients died during the period of follow-up. In two, death resulted from complications of uremia; in the remaining patient death was caused by carcinoma of the lung with brain metastases.

CONCLUSIONS

1. Despite the development of more effective uricosuric agents for the control of the manifestations of gout, there still remain patients who fail to respond to therapy and in whom crippling deformities develop.

2. An analysis of twenty-one patients indicates that a carefully planned surgical program may offer lasting benefits in tophaceous gout of the upper extremity.

3. Large deforming masses of tophaceous material can be advantageously removed.

4. Digital function may be significantly improved.

5. Chronic infections can be better controlled.

6. Disabilities resulting from tophaceous deposits in the flexor tendons may be corrected by resecting the involved portion of tendon or excising the tophaceous mass.

NOTE: The authors wish to express their appreciation to Dr. William H. Kammerer for his valuable assistance in the preparation of this paper.

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DISCUSSION

Dr. George S. Phalen, Cleveland, Ohio: Dr. Straub, Dr. Smith, Dr. Carpenter, and Dr. Dietz have given us an excellent review of the subject of tophaceous gout, especially as it applies to the upper extremity. As they pointed out, improvement or restoration of function should be the primary indication for the surgical treatment of gout in the hand—not the eradication or control of the local disease process. Early incision of a tophus, as a prophylactic measure to prevent joint or tendon damage, is now seldom, if ever, indicated with the use of the excellent uricosuric drugs we now have at our disposal.

One must be very cautious in recommending surgical treatment of gout in the hand purely for cosmetic restoration. Incomplete removal of the tophus will still leave the finger with an abnormal contour; and, if the surgeon becomes too aggressive in his attempt to excise the tophus completely, the end result will be a finger that looks better but one that has poorer function. This is the sort of thing that litigation thrives on. Dr. Straub, Dr. Smith, Dr. Carpenter, and Dr. Dietz have stressed the importance of not removing the tophus completely if such a procedure entails the sacrifice of an essential structure.

I was especially interested in the cases of carpal-tunnel syndrome which the authors described in this report. Several years ago, Dr. Paul Lipscomb first brought to my attention the possibility of compression of the median nerve in the carpal tunnel by deposits of uric-acid crystals. I have been patiently watching for such a case to come my way, but I have not had the opportunity of operating on such a case myself.

(Continued on page 774)

Restoration of Rheumatoid Finger-Joint Function

Interim Report on Trial of Prosthetic Replacement *

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In recent years there has been increasing interest in rheumatoid disease of the hand [5,6,7,8,9,10]. A plan of action is being slowly evolved which will correct or alleviate most of the soft-tissue deformities of the hand in rheumatoid arthritis. However, destruction of the joints of the digits remains an unsolved problem. This paper is an interim report from the University of Iowa on the trial of a metallic articulated prosthesis used for the replacement of the metacarpophalangeal and proximal interphalangeal joints destroyed by rheumatoid disease.

The work was originally stimulated by the observation that many hands with

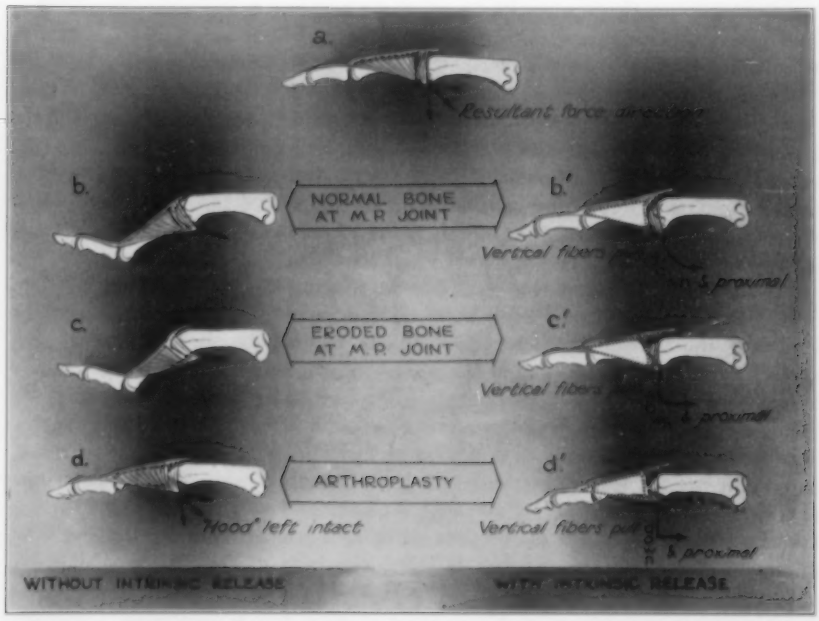

FIG. 1

Dislocation of the metacarpophalangeal joint. *A:* The resultant of the forces exerted by the intrinsic muscles through the vertical fibers of the intrinsic hood and the insertion of these muscles on the base of the proximal phalanx is in a palmar and proximal direction. This is the direction in which dislocation occurs with rheumatoid involvement of this joint. *B-B':* When the joint surfaces are normal this dislocating force is still present even when the usual intrinsic-release operation is performed. *C-C':* Long-standing disease in this joint changes the articular surfaces so that they become parallel with the plane of the resultant pull shown in *A*. The usual intrinsic-release operation (*C*) does not overcome the tendency to continuing dislocation. *D-D':* Arthroplasties which modify the shape of the metacarpal head do not remove the dislocating force of the intrinsics, even when the usual intrinsic release is performed. It would seem that in rheumatoid disease the intrinsic-release operation must be more extensive and should remove all factors contributing to the palmar and proximal dislocation of the base of the proximal phalanx.

* Read in part at the Annual Meeting of the American Society for Surgery of the Hand, Miami Beach, Florida, January 6, 1961.

intrinsic-plus deformities † caused by rheumatoid arthritis did not regain a functional range of movement following surgical release of the intrinsic contracture by the excision of a triangular portion of the intrinsic tendon on each side of the extensor hood (Fig. 1). It was assumed that these fingers had been in the deformed position for so long that secondary joint changes had taken place (Figs. 6-A and 7-A). This observation is in accord with the observation of Laine and his colleagues that the deformity seems to occur in the more advanced stages of rheumatoid disease. In some hands, joint contractures and intra-articular adhesions prevented movement of the fingers. In others, bone deformity had occurred at the articular surface, and in a few, bone fusions had taken place. Some of the patients did not obtain a very great range of motion after intrinsic release but did, nevertheless, gain sufficient function to obviate further surgery. In many of those who did not regain satisfactory function, it appeared that further improvement might be obtained either by fusion or by trial replacement of the joint with a prosthesis.

Although involvement of the intrinsic muscles of the hand is common in rheumatoid disease, with the development of so-called swan-neck deformities, this disease is not the only cause of the deformity. Vaughan-Jackson showed that diminished action of the flexor sublimis, inherent inability to extend the metacarpophalangeal joints fully, congenital predisposition to hyperextension of the proximal interphalangeal joint, and disturbance of the flexor-extensor muscle balance by wrist dislocation, all may produce the swan-neck deformity.

An established swan-neck deformity is so crippling that usually something must be done to restore the destroyed longitudinal arch of the hand. One hesitates to fuse the proximal interphalangeal finger joint because movement of this joint is of such fundamental importance. Fusion of this joint is perhaps more acceptable when it is the only joint involved, but in the fingers of many patients with rheumatoid disease there is also damage to the metacarpophalangeal joint.

In the early stages of this work it was thought that there would be little indication for prosthetic replacement of the metacarpophalangeal joint, particularly since the arhtroplasties of this joint in vogue at the time seemed to give satisfactory results. As more experience was gained, however, it became obvious that many of these joints after arthroplasty were losing their stability as time progressed. In addition, during the follow-up of patients with interphalangeal-joint prostheses, it was disturbing to find some patients with good motion of the prosthetic joint steadily losing function of the hand because of dislocation of the metacarpophalangeal joints.

The difficulty in these cases appeared to be a recurrence of the original dislocation of the metacarpophalangeal joint, the base of the proximal phalanx moving palmarward and proximally, with the result that the keystone of the longitudinal arch of the hand was broken and the power of flexion dissipated. The exact cause of this recurrent dislocation is not known but it seems probable that it is caused by the action of the intrinsic muscles. Through their tendon attachment to the base of the proximal phalanx and the vertical fibers of the hood, force is exerted in the direction of the continuing dislocation (Fig. 1). This possibility suggests that a more extensive intrinsic release is indicated, including the vertical fibers which are usually preserved because of their flexor action on the metacarpophalangeal joint.

Ulnar drift presents an additional problem at the metacarpophalangeal joint. Once the long extensor tendons are dislocated to the ulnar side of their respective joints, progression of the drift inevitably follows. When this displacement is com-

† The term *intrinsic-plus* was coined by the late Sterling Bunnell to describe the so-called pill-roller deformity which is produced by constant overaction or fibrous contracture of the intrinsic muscles.

bined with a palmar subluxation of the base of the proximal phalanx, the metacarpophalangeal joints become completely disrupted and the digits on the ulnar border of the hand lie at 90 degrees to the longitudinal axis of the hand (Fig. 9-A).

Fusion of the metacarpophalangeal joints, especially of the fingers on the ulnar side of the hand, is recommended as a means of supplying stability. A splint is thus provided for the radial digits to prevent them from drifting further. Unfortunately, this rigid splint can only supply stability in one position. In all other positions the movable fingers can displace ulnarward either dorsally or volarly to the fused fingers. If, however, the metacarpophalangeal joints are replaced by prostheses, lateral stability is supplied in all degrees of available flexion at the metacarpophalangeal joint, and excellent function can be restored (Fig. 9-B). In addition to flexion and extension, the normal metacarpophalangeal joint has a range in abduction and adduction. This movement is not possible after the insertion of a prosthesis, but it has been found that the stability supplied to the joint more than compensates for the loss of abduction and adduction.

While fusion may be acceptable treatment for a single joint in an otherwise normal hand, the procedure may be contra-indicated in rheumatoid arthritis, which usually involves all the soft tissues of the hand with varying degrees of severity throughout the years. It follows that while a decision to fuse a joint or joints may be proper at one time, conditions may change so that the fused joints become more of a liability than an asset. If, on the other hand, a prosthesis can be used successfully, then the retention of a stable joint with a useful range of motion should have a beneficial effect on the function of the hand in the future.

Prosthetic replacement of finger joints cannot be considered as an isolated undertaking without reference to the function of the other two joints of the digit or of the hand as a whole. At the proximal interphalangeal joint, the condition of the intrinsic muscles is of fundamental importance. It is useless to restore a destroyed joint with a prosthesis unless the primary cause of the swan-neck deformity is eliminated. Because of the frequency of direct involvement of the intrinsic muscles by the disease, it is our almost invariable practice to do an intrinsic release at the time that the prosthesis is inserted. In some patients prostheses are indicated after an intrinsic release has failed to give full movement. In such cases it is always wise to explore the intrinsic mechanism at the time of the placement of the prosthesis to ensure that all the deforming fibers of the hood have been removed.

At the level of the metacarpophalangeal joint, distortion of the hood and ulnar dislocation of the extensor tendons have usually occurred before the patient is seen. It is illogical to place a prosthesis in one or more of the metacarpophalangeal joints without, at the same time, correcting deformities in the adjacent joints. It is our practice, therefore, to approach all these joints through a dorsal transverse incision and to perform synovectomies of the joints which are not replaced by prostheses. In all four finger joints, the dislocated extrinsic extensor tendons are replaced in the mid-line of the digits. A simple and efficient method to perform the synovectomy and to reposition the extensor tendon is to approach each joint through an incision in the hood on its radial side. This incision is made parallel to the extensor tendon and about one-quarter inch from the tendon. Even with extensive disease, a plane of cleavage is usually found between the hood and the underlying capsule. When doing the synovectomy, particular care must be taken to remove the tongues of synovial tissue which lie between the collateral ligaments and the sides of the metacarpal head. If these tongues of tissue are not removed they frequently cause recurrent symptoms.

After the synovial tissue has been removed, the shortened fibers on the ulnar side of the hood must be incised to allow the extensor tendon to be replaced in the

mid-line on the dorsum of the joint. With the tendon replaced, it will be found that the incised hood on the radial side can be overlapped or double-breasted and two rows of black silk sutures placed to retain the tendon in the corrected position. When the joint of the index finger is not to be replaced by a prosthesis then the extensor indicis proprius tendon is transferred into the tendon of the wasted first dorsal interosseus muscle to reinforce its action.

INDICATIONS

There is a functional relation between the proximal interphalangeal and metacarpophalangeal joints in the normal finger; in the diseased finger, this interrelation becomes vitally important. Rheumatoid disease is so capricious and catholic in its manifestations that when a single joint of a digit is involved every attempt should be made to restore normal function in this joint in case other joints of the digit subsequently become involved.

Adequate muscle control is a prerequisite to any joint reconstruction. In rheumatoid disease of the finger joints, it is extensor power that is usually in question; it is uncommon for flexor power to be absent. Indeed, the flexor power is usually greatly in excess of the extensor power. The extensor mechanism is frequently involved because the expanding synovitis can extend dorsally more easily than in the palmar direction, where the strong volar plate prevents involvement of the flexor tendons. Once the extensor mechanism within a finger is disrupted, little can be done to restore its function. Successful reconstruction of this mechanism, when the tissues are normal, is rare; in rheumatoid disease, I have never achieved a satisfactory reconstruction.

It is my current belief that, if the tendon mechanism of a digit is intact, the indications for prosthetic replacement of the proximal interphalangeal joint are: (1) gross joint destruction, (2) persistent swan-neck deformity, and (3) ankylosis of the joint in a non-functional position. These indications are reinforced if there is dysfunction of the related metacarpophalangeal joint.

At the metacarpophalangeal joint, if the tendon mechanism is intact even though displaced, the indications for prosthetic replacement are: (1) gross joint destruction, (2) palmar dislocation of the joint, and (3) persistent ulnar drift combined with joint destruction or palmar dislocation.

Ulnar drift, by itself, is not considered an indication for prosthetic replacement at the metacarpophalangeal joint. If joint destruction or dislocation has not occurred, ulnar drift can be treated satisfactorily by synovectomy, reposition of the extensor tendons, and reinforcement of the action of the first dorsal interosseus muscle by tendon transfer.

There is no functional contra-indication to replacement of several finger joints within the same hand; replacement of both the metacarpophalangeal and proximal interphalangeal joints in the same hand has been carried out. However, replacement of these two joints in one digit would appear to be a formidable undertaking and has not been attempted. In the thumb, the metacarpophalangeal joint has been replaced by a prosthesis, but not the interphalangeal joint.

CONTRA-INDICATIONS

Boutonnière deformity of a finger must be considered a contra-indication to prosthetic replacement of the proximal interphalangeal joint. It was hoped at first that reconstruction of the extensor-mechanism at the time that the prosthesis was inserted would give satisfactory results, but follow-up of the patients in whom reconstruction was attempted has shown recurrence of the deformity. It now appears that fusion of the proximal interphalangeal joint in the functional position

is the most satisfactory procedure for the treatment of a boutonnière deformity in rheumatoid arthritis.

Long-standing flexion deformity of the proximal interphalangeal joint has the same effect as a boutonnière deformity. Constant pressure of the joint surfaces against the undersurface of the extensor mechanism so thins and stretches the tendon, that the extensor muscles can no longer balance the flexor muscles. Bitter experience has shown that, under these circumstances, the extensor mechanism cannot control the joints if mobility is restored by prosthetic replacement. Fusion in the functional position is a better operation.

Still's disease may produce severe deformities of the hand. Unfortunately the bones in these patients, when they have completed their growth, are usually much smaller than the average, and attempts to place prostheses in these hands have been uniformly unsuccessful (Case 2, Figs. 5-A and 5-B).

It must be stressed that the mere presence of the features described as indications does not necessarily justify operation. It is the over-all function of the hand and the use which the patient makes of it that are important. It is absolutely wrong to operate on a patient who expresses no desire to obtain improved function. Such a person is unlikely to cooperate after operation.

EXPERIENCE WITH PROSTHESIS

Prosthetic replacement is no cure-all; it should not be undertaken lightly. Certainly it is not indicated in every patient with rheumatoid involvement of the finger joints. In the last three years, fifty-four patients have submitted to 101 operations on their hands. Many of these operations included several different procedures performed under one anesthesia. The totals recorded in Table I represent the sums of the separate procedures. Thus, if an intrinsic release and a synovectomy of the metacarpophalangeal joints were performed, each was considered a statistical unit making a total of two. On the other hand, if the same procedure was performed on more than one digit (that is, synovectomy of four metacarpophalangeal joints at one operation), this was tabulated as a single procedure. The prostheses were an exception to this method of tabulation. The figures for prostheses represent the total number of individual prostheses inserted. By this method of tabulation, proximal interphalangeal-joint prostheses constituted 14 per cent and metacarpophalangeal-joint prostheses less than 12 per cent of the total number of operations performed. Thus, even though the statistics are weighted in favor of the prostheses by this method of tabulation, these still constituted only a small proportion of all the procedures performed. These figures emphasize the relatively few indications for and the restricted application of these prostheses.

TECHNIQUE

Several prostheses are available for use, and three types were tried in the proximal interphalangeal joint in this series (Figs. 2-A and 2-B).

At first, the original Brannon prosthesis was used but experience showed that this design was not satisfactory for these patients. The chief problem was rotation of the single tapering stem within the medullary canal (Fig. 2-B). Eventually, a stainless-steel prosthesis (SS 316) with a two-pronged stem was evolved which, at the time of writing, is the standard design for both the proximal interphalangeal and the metacarpophalangeal joints (Fig. 3). Four sizes of prostheses are currently available, two for each joint, with the larger ones used in men. The prongs are made long enough for the largest hand, but they can be shortened conveniently with wire-cutters.

TABLE I

Intrinsic release	25
Extensor-tendon reposition	18
Extensor-tendon repair (boutonnière)	3
Extensor-tendon graft	1
Extensor-tendon shortening (with prosthesis)	2
Transfer of extensor indicis proprius to first dorsal interosseus	12
Transfer of extensor indicis proprius to extensor pollicis longus	4
Synovectomy of extensor tendons	4
Synovectomy of flexor tendons	2
Anti-Rh* injection of metacarpophalangeal joint	2
Synovectomy of metacarpophalangeal joints	15
Arthroplasty of metacarpophalangeal joints	13
Fusion of metacarpophalangeal joints	5
Metacarpophalangeal-joint prosthesis	26
Synovectomy of metacarpophalangeal joint of the thumb	2
Anti-Rh* injection of proximal interphalangeal joints	3
Synovectomy of proximal interphalangeal joints	2
Arthroplasty of proximal interphalangeal joints	1
Fusion of proximal interphalangeal joints	13
Prosthesis of proximal interphalangeal joints	31
Removal of prosthesis	6
Revision of prosthetic joint	5
Thumb-joint fusion	4
Wrist-joint fusion	4
Excision of rheumatoid nodule of digit	3
Excision of rheumatoid nodule of forearm or elbow	6
Manipulation of fingers	5
Muscle biopsy	2
Lengthening of flexor tendons at wrist	1
Reattachment of lateral bands	3
Release of trigger-finger	1
Recession of thumb abductor and adductor	2
	226

* Intra-articular injection of an alkylating agent (nitrogen mustard derivative).

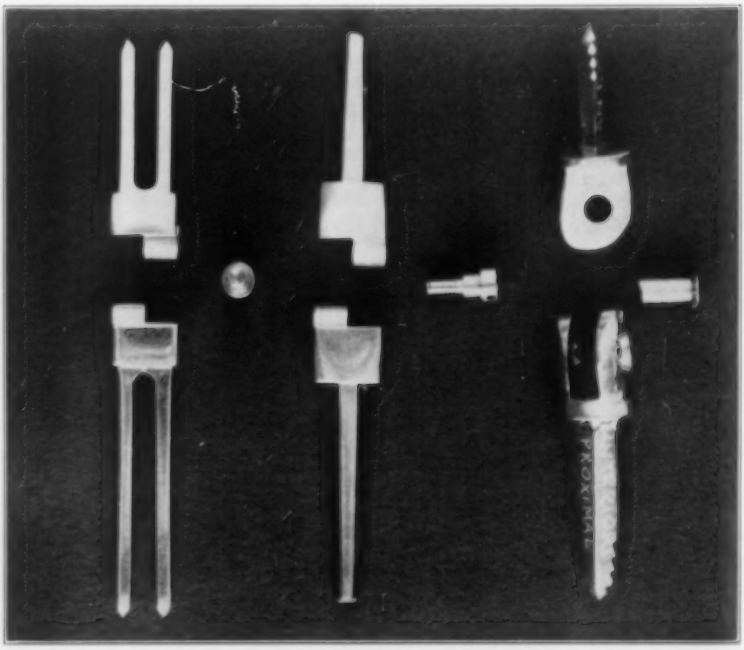

FIG. 2-A

FIG. 2-B

Figs. 2-A and 2-B: Prostheses used. Three different types of prostheses have been used in the proximal interphalangeal joints.

Fig. 2-A: An exploded view of the three prostheses: the single-stem Brannon type is in the center, to its left is the current two-pronged modification, and to the right is the Richards type of prosthesis.

Fig. 2-B: The three prostheses in place within one hand. Note the rotation of the middle phalanx of the long finger around the single stem of the prosthesis and the ulnar shift of the relatively short stem of the Richards prosthesis within the proximal phalanx of the ring finger.

Special tools are needed for the insertion of the prosthesis since care must be taken not to damage the articular surfaces of the prosthesis (Fig. 3). A dorsal transverse incision is used for the metacarpophalangeal joint and a lateral finger incision for the proximal interphalangeal joint (Figs. 4-A and 4-B).

The joint to be replaced is most easily approached by excising one collateral ligament and dislocating the joint laterally. The joint surfaces should be removed piecemeal with rongeurs; bone cutters may splinter and destroy more bone than is desirable.

The most difficult problem is to decide how much bone to resect. Experience has shown that if an amount equal to the length of the hinge is removed, the finger may tend to be stiff and hard to move. The best guide is to remove one to three millimeters more bone than is needed to accommodate the prosthesis. When this is done, the joint will be slightly floppy at first, but good control over the finger will be obtained after the muscles have taken up the slack.

Usually it is not difficult to insert the two-pronged stems within the medullary canals, since the prongs spring sufficiently to adapt to the diameter of the canal. When the diameter of the canal is too small, as it may be in the mid-portion of the shaft, a drill, or preferably a long-shaft dental burr, may be used to widen the canal. When the phalanges or metacarpals are extremely slim, there appears to be no clinical disadvantage to deliberately passing the prongs out through the cortex for a short distance in the region of the narrow waist of the bone and then back

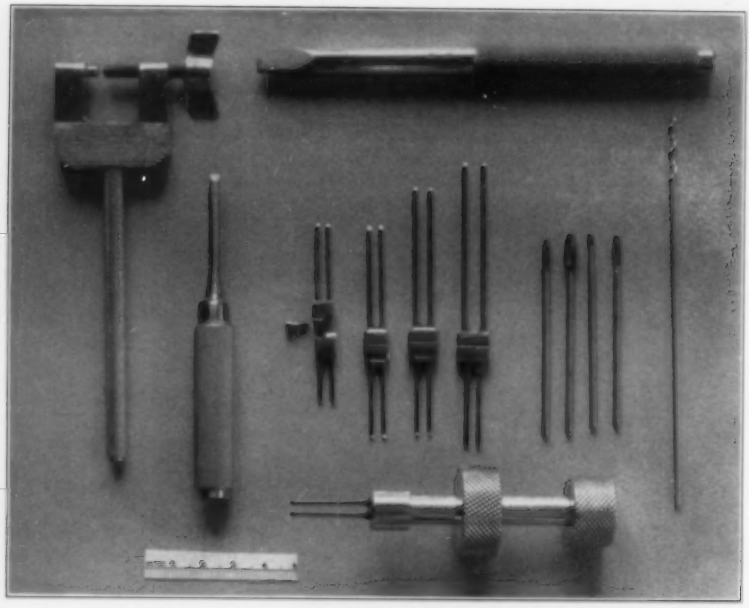

FIG. 3

Instruments for prosthesis insertion. At the bottom is the broach used to test the medullary canal prior to insertion of the prosthesis. At the top is the impactor shaped to articulate exactly with one-half of a prosthesis while it is hammered into place. On the left is the crimping tool used to expand the hollowed end of the screw. Also shown are the screw driver, the four different sizes of the prosthesis, the 5/64-inch drill used to drill the bone to receive the prongs of the prosthesis, and the long-shanked dental burrs used to ream out the medullary canal when this is indicated.

FIG. 4-A

FIG. 4-B

Figs. 4-A and 4-B: Surgical approaches.

Fig. 4-A: For the interphalangeal prosthesis, the approach is through the neutral border of the finger.

Fig. 4-B: The best approach for the variety of procedures necessary at the metacarpophalangeal joint is the transverse incision. If a single digit is to be operated on a mid-line dorsal curvilinear approach is permissible.

into the bone proximally or distally, as the case may be. It makes no difference which half of a prosthesis is placed first, but great care must be taken to align the two halves of the prosthesis correctly in relation to the alignment of the finger.

When placing the proximal portion of the prosthesis, its flat dorsal surface must be parallel with the flattened distal upper surface of the metacarpal or proximal phalanx. Similarly, the distal half of the prosthesis must be placed with its dorsal surface parallel with the plane of the fingernail.

When both portions of the prosthesis have been properly aligned, they are driven home with the special impactor. The screw is then inserted and its cone-shaped hollow end is crimped with the special instrument designed for this purpose.

After operation, the fingers are splinted in the position of function until the incisions are healed. Sutures are removed about ten days after operation if wound healing is sound; all dressings are left off. Movement is encouraged immediately. The transverse metacarpal incision frequently takes a few more days to consolidate; and, in general, movement is not started until the fourteenth day. Usually, no difficulty is encountered in obtaining flexion in the joints, but full extension may be difficult to achieve. Progressive-resistance exercises to build up the strength of the finger extensors are frequently indicated. Occupational therapy devised to correct this lack of extension is useful but should be directed toward some domestic or occupational task which the patient had previously been unable to accomplish.

ILLUSTRATIVE CASES

Interphalangeal Prostheses

CASE 2. M.A., a secretary, eighteen years old, was first considered for possible surgery ten years after the onset of Still's disease. Her hands were first affected at the age of thirteen. The right hand showed gross, fixed flexion contractures of the proximal interphalangeal joints and had almost no grasp. Prostheses were placed in the proximal interphalangeal joint of the long finger, and five weeks later in the same joint in the ring finger.

The skin over the dorsum and ulnar side of the ring-finger prosthesis sloughed, and the prosthesis was removed three weeks after insertion (Fig. 5-A). The joint was subsequently successfully fused in functional position. The prosthesis in the long finger retained some movement for about three months, but the finger gradually returned to its original grossly flexed position, and the patient obtained no functional improvement. Technically the operations were extremely difficult because of the small size of the bones, and the proximal and middle phalanges of the ring finger were split during the insertion of the single-stemmed prosthesis (Fig. 5-B). Similar small-sized phalanges have been seen in other patients with Still's disease; and, in general, it is now considered inadvisable to attempt to insert a prosthesis in such small bones.

CASE 3. S.V., a housewife, sixty-five years old, was crippled by generalized arthritis, which she had had for twenty years. Both hands showed gross involvement of the intrinsic muscles, with wasting of both first dorsal interosseus muscles and fibrosis of the remaining interossei. Both hands showed ulnar drift of the fingers and destruction of the metacarpophalangeal joints; but her greatest handicap was fixed swan-neck deformities of the fingers. The proximal interphalangeal joints were so hyperextended that she was unable to grasp any object and could not do any domestic tasks, such as washing dishes or wringing out a face cloth.

An intrinsic release was performed on the fingers of the left hand without any increase in function. The proximal interphalangeal joints of the long and ring fingers of the right hand were then replaced by prostheses, and one month later three prostheses of different types were inserted in the proximal interphalangeal joints of the index, long, and ring fingers of the left hand (Fig. 2-B). Twenty-six months after operation, the prostheses in the right hand were working well. In the left hand, twenty months after operation, the middle phalanx of the long finger had rotated on the stem of the prosthesis, and there was very poor movement in both the long and ring fingers. It was thought that this poor movement might have been produced by inadequate resection of bone, and seventeen months before the time of writing revisions of the prosthetic joint in these two fingers were carried out. No demonstrable gain in function was obtained in the ring finger.

The two-stemmed prosthesis in the right index finger worked well and the patient requested that a similar type be substituted for the prosthesis in the ring finger. Fifteen months after this was done, function of the ring finger was better and function of both hands was greatly improved over that present before operation (Figs. 6-A, 6-B, and 6-C). This patient is no longer totally dependent

FIG. 5-A

FIG. 5-B

Figs. 5-A and 5-B: Complications in Still's disease, Case 2. The bones in Still's disease are so small that it is extremely difficult to insert even the single-stem prosthesis. In this patient, one prosthesis was adequately inserted in the long finger; but, in the ring finger, fractures of both phalanges were produced and the skin sloughed (Fig. 5-A) over the displaced unstable prosthesis (Fig. 5-B).

FIG. 6-A

Figs. 6-A through 6-C: Mixed types of prosthesis in one patient, Case 3.
Fig. 6-A: Swan-neck deformities and destruction of the proximal interphalangeal joint in both hands.

on her daughter; she attends to all her toilet requirements, washes dishes, wrings out her wash cloth, and recently has started earning money by selling crochet-work which she is now capable of making.

CASE 5. D.J., a housewife, forty-four years old, had had rheumatoid arthritis for nine years and hand symptoms for six years. The left hand was particularly involved with severe fixed intrinsic-plus deformities (Fig. 7-A). She was unable to make a fist and could use the hand only as a flat plate. Intrinsic release in all the fingers, three and a half years before the time of writing, resulted in no permanent gain in function and fourteen months later two-stemmed prostheses were placed in the proximal interphalangeal joints of the index, long, and ring fingers (Fig. 7-B). A dramatic increase in function ensued, and the patient insisted that prosthetic replacement of the same joint of the little finger be attempted. A prosthesis with shortened stems was inserted in the little finger (Fig. 7-C), with the result that function of her hand sixteen months after operation on the index, long, and ring fingers and nine months after operation on the little finger was excellent (Fig. 7-C). Her hand was changed from a flipper to a useful prehensile organ. The patient was enthusiastic and felt that she was still gaining strength of grip.

Metacarpophalangeal and Interphalangeal-Joint Prostheses

CASE 6. H.H., a doctor's secretary, forty-eight years old, had had rheumatoid involvement of both hands for twenty years (Fig. 8-A). The left hand showed a fixed boutonnière deformity of the index finger with relatively little involvement of the other digits. In the right hand, there were

FIG. 6-B

The two single-stemmed prostheses in the right hand have been in place for twenty-six months. In the left hand, the prostheses have been in place in the index and long fingers for twenty-five months and in the ring finger for fifteen months. Note that the prostheses, especially in the right hand, appear to be sinking into the phalangeal shafts.

rapidly increasing subluxations of the metacarpophalangeal joints of the index and long fingers. Since the left index finger was virtually useless, she wished to have a trial of a prosthesis, even though she was given a gloomy prognosis. The prosthesis was inserted and the extensor mechanism was restored as well as possible by suturing the lateral bands so that they lay dorsal to the axis of motion of the joint. For three months after operation she was able to extend fully and to flex partially the proximal interphalangeal joint, but thereafter the boutonnière deformity recurred, and fifteen months after operation the finger again was useless (Fig. 8-B). It is planned to remove the prosthesis and to fuse the joint in the functional position. Five and one-half months before the time of writing, the right hand became so incapacitated that in spite of the previous failure she requested prostheses in this hand. Prostheses were placed in the metacarpophalangeal joints of the index and long fingers (Fig. 8-C). Using a transverse incision, synovectomies of the other metacarpo-

FIG. 6-C

The outer hand casts were made before operation, when the patient was holding the metacarpophalangeal joints extended and attempting to flex the proximal interphalangeal joints. The inner casts were made before the prosthesis in the left ring finger was changed to the two-pronged type, while the same movement was attempted.

FIG. 7-A

Figs. 7-A through 7-D: Persistent intrinsic-plus deformity of the hand, Case 5.
Fig. 7-A: In a hand with fully developed swan-neck deformities of the fingers, there is no flexion of the proximal interphalangeal joints and, hence, gross impairment of grasp.

phalangeal joints were performed and the extensor tendons replaced. This patient is back at work and reports that she feels great confidence in her right hand and that five and one-half months after operation it is stronger than it has been in years.

Metacarpophalangeal-Joint Prostheses

CASE 7. S.A., an executive, fifty-two years old, had rheumatoid arthritis for thirty-two years before surgery. Many joints were affected but during the five years before operation his hands had been "faliing to bits" (Fig. 9-A). Recently, he had found it difficult to write and impossible to grasp door handles or other similar objects. He considered his hands to be a handicap in his daily

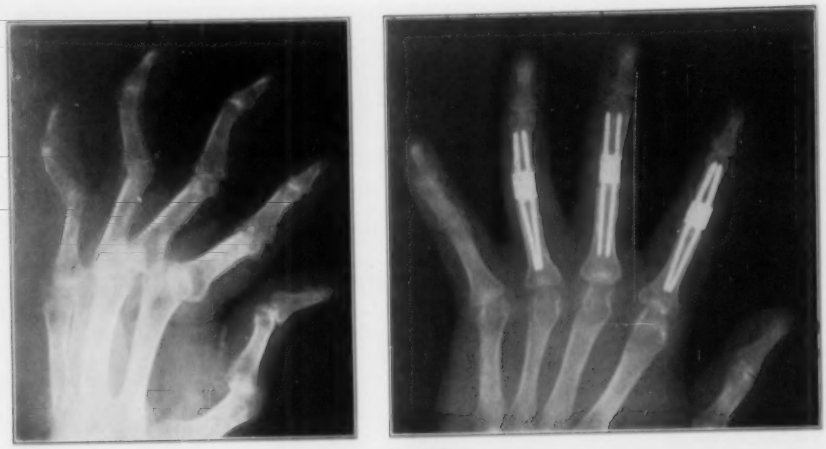

FIG. 7-B

Roentgenograms of the hand immediately before and nineteen months after insertion of three prostheses which were placed in the proximal interphalangeal joints.

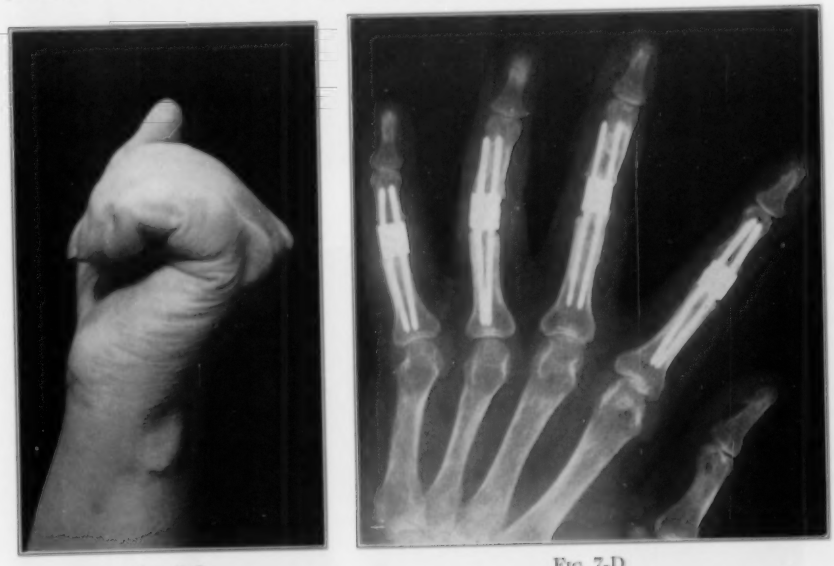

FIG. 7-C

FIG. 7-D

Fig. 7-C: Finger flexion, nine months after a fourth prosthesis was placed in the little finger. The roentgenogram and photograph show the present state of the bones and the function of the hand.
Fig. 7-D: Roentgenogram made at the same time as the photograph in Fig. 7-C. Note that the middle phalanx of the long finger shows some bone absorption around the prongs of the prosthesis (compare Figs. 7-B and 7-D).

contact with people. In his dominant right hand, prostheses were inserted into the metacarpophalangeal joints of the ring and little fingers through a transverse incision. Synovectomies of the two radial metacarpophalangeal joints and replacement of all extensor tendons were also carried out (Fig. 9-B). Eleven months after operation, the patient reported "a virtually normal hand". He could shake hands with confidence and ease and recently had volunteered his service as a speaker for the local chapter of the Arthritis and Rheumatism Foundation.

CASE 4. D.E., a retired schoolmistress, sixty-four years old, had had arthritis for at least thirty-five years. There was ulnar drift of the fingers and many joints were involved in both hands. In the right hand, the metacarpophalangeal and proximal interphalangeal joints of the ring and little

FIG. 8-A

Figs. 8-A, 8-B, and 8-C: Interphalangeal and metacarpophalangeal-joint prostheses, Case 6.
Fig. 8-A: Roentgenograms show the boutonnière deformity of the left index finger and the dislocation and destruction of the metacarpophalangeal joints of the right index and long fingers.

FIG. 8-B

A prosthesis was placed in the proximal interphalangeal joint of the left index finger, but function was not restored and the deformity recurred. Note the longitudinal fracture of the proximal phalanx, produced when the prosthesis was inserted; despite this complication, the prosthesis was completely stable within the bone.

FIG. 8-C

Prostheses placed in the metacarpophalangeal joints of the right index and long fingers. Five and one-half months after operation, this hand had a very satisfactory degree of function.

fingers were surgically fused to correct gross deformities. Subsequent follow-up showed that the index and long fingers were continuing to drift in an ulnar direction. Single-stemmed prostheses were placed in the metacarpophalangeal joints of these two fingers to provide stability in grasp and to prevent these fingers from displacing in an ulnar direction either dorsally or volarly to the two fused fingers.

The patient was sufficiently pleased with the results of the prostheses in the right hand to request surgical treatment for the increasing ulnar drift in the left hand. Examination showed that the greatest destruction had occurred on the radial side of the hand, and a prosthesis was placed in the metacarpophalangeal joint of the index finger, and synovectomies of the other metacarpophalangeal joints with repositioning of all extrinsic tendons were carried out. Follow-up is only eight months, but the ulnar drift remains corrected and the hand is functioning well.

REVIEW OF RESULTS

Prosthetic replacement of finger joints is not new. Brannon described the use of his prosthesis in fourteen patients with traumatic destruction of proximal interphalangeal joints two years ago [1]. In the present study, a modification of his original design has been applied in a generalized disease of the hand. The results of prosthetic replacement of one joint in an otherwise normal hand are easy to evaluate. In rheumatoid disease of the hand, however, the whole part is commonly affected; prosthetic replacement is usually only part of the total surgical procedure. It is therefore difficult to quantitate what portion of the total functional result is due to the prosthetic replacement of a single joint. The results of thirty-one prostheses which have been in place for six months or more are shown in Table II. A total of twenty-three prostheses were placed in the proximal interphalangeal joint and eight in the metacarpophalangeal joint. Fourteen have been in place for one year or more.

FIG. 9-A

Figs. 9-A, 9-B, and 9-C: Replacement of the metacarpophalangeal joints of the ring and little fingers, Case 7.

Fig. 9-A: Roentgenogram of the hand prior to surgery; this grotesque deformity had developed in the short space of nine months.

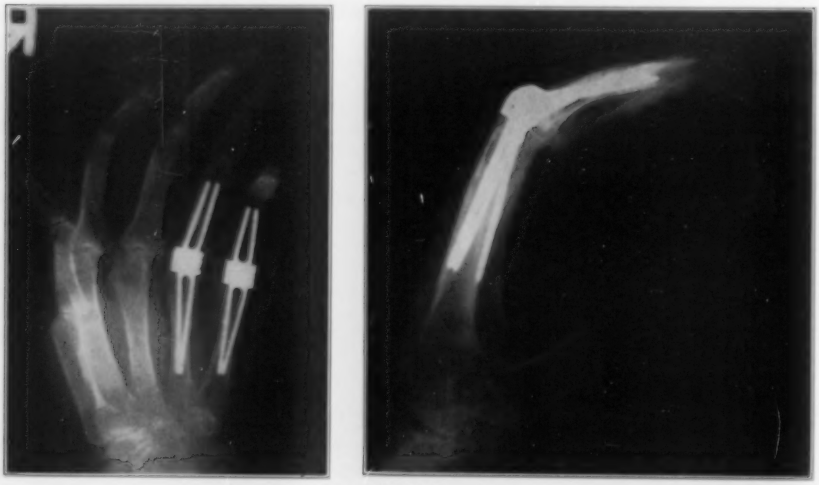

FIG. 9-B

The dislocated metacarpophalangeal joints of the ring and little fingers were replaced by prostheses. These roentgenograms were made eleven months after insertion of the prostheses. Note how the prongs adapt to the internal diameter of the metacarpal and phalangeal shafts. The lateral view shows the maximum active flexion from full extension.

Complications

For the early trials of the prosthesis, patients with crippling deformities were chosen deliberately so that no further damage to hand function could be done if the procedure failed. While ethically correct, this policy did not provide a fair test of the procedure. Most of the poor results recorded in this series were in these early cases.

FIG. 9-C

Casts of the right hand showing gross ulnar drift of all the fingers before operation (right) and the hand making a fist after insertion of the prostheses (left). Note how the index and long fingers are helped to remain in good position by the movable splinting provided by the ring and little fingers.

At the time of writing, a total of fifty-seven prostheses have been placed in the proximal interphalangeal and metacarpophalangeal joints. The great majority of these have proved to be satisfactory, and no mechanical troubles have occurred to warrant change in the design of the prosthesis. In two cases, the screw joining the two halves of the prosthesis worked loose and had to be replaced. Examination of the screws showed that failure was due to a manufacturing error. The hole in the end of the screw was cylindrical rather than conical. As a result, during crimping, the final thread of the screw was broken off from the shaft instead of being expanded into a flare, like the end of a rivet.

Six prostheses have been removed from the proximal interphalangeal joint as follows:

1. One prosthesis was removed because of infection, which developed five weeks after the operation, when the patient impaled the finger directly through the incision on the sharp end of a metallic coat hanger.

2. In one patient (Case 2, Figs. 5-A and 5-B) the skin overlying the prosthesis sloughed. In this finger, the proximal and middle phalanges were fractured when the prosthesis was inserted and the prosthesis was unstable in both bones.

3. One prosthesis, not the standard two-pronged type, was removed because of lack of active movement of the joint, although passive movement was possible at the time of insertion (Case 3, Fig. 2-B). It is possible that this failure was due to a technical error since subsequent replacement by a standard two-pronged prosthesis yielded good active movement.

4. In another patient, three prostheses were inserted into three proximal interphalangeal joints which had been fixed in flexion for a prolonged period. Absolutely no voluntary movement was gained despite adequate resection of bone. All three prostheses were removed and the joints were fused in the functional position. It is evident that when flexion deformities are of long standing, the extensor power is insufficient to balance flexor power after motion is restored by a prosthesis.

TABLE II

Case	Age at Operation (*Years*)	Preoperative Condition	No. of Prostheses Used	Joint Replaced Joint	Side	Finger	Follow-up (*Months*)
1. W.M.	62	Boutonnière deformity; $\frac{2}{3}$ normal range of passive motion	1	PIP	L	Long	34
2. M.A.	18	Still's disease; volar subluxation and severe PIP joint-flexion deformities	2	PIP	R	Long	28
				PIP	R	Ring	28
3. S.V.	65	Fibrous ankylosis of PIP joints; swan-neck all fingers both hands	5 (1) *	PIP	R	Long	26
				PIP	R	Ring	26
				PIP	L	Index	25
	65			PIP	L	Long	25
				PIP	L	Ring	25
	66	Failure of prosthesis; no motion		PIP	L	Ring	15
4. D.E.	64	Dislocation and destruction of MP joints; jog of voluntary movement	3	MP	R	Index	24
				MP	R	Long	24
	65	Gross ulnar drift; complete dislocation and destruction MP joint		MP	L	Index	8
5. D.J.	44	Ulnar drift and fixed swan-neck deformities of all fingers	3	PIP	L	Index	19
				PIP	L	Long	19
				PIP	L	Ring	16
	45	Fixed swan-neck deformity	1	PIP	L	Little	9
6. H.H.	48	Boutonnière deformity of index finger; no voluntary movement	1	PIP	L	Index	15
7. S.A.	52	Ulnar drift; complete dislocation of all MP joints	2	MP	R	Ring	11
				MP	R	Little	11
8. S.M.	58	Fixed swan-neck deformity of fingers	3	PIP	R	Index	9
				PIP	R	Long	9
				PIP	R	Ring	9
9. C.E.	57	Flexion contractures with intra-articular adhesions; jog of voluntary movement only	3	PIP	L	Index	6
				PIP	L	Long	6
				PIP	L	Ring	6
10. H.I.	55	Extensive destruction index MP joint and its constituent bones	1	MP	R	Index	9
11. O.M.	63	Fibrous ankylosis of PIP joints in full extension	3	PIP	L	Index	9
				PIP	L	Long	9
				PIP	L	Ring	9
12. M.L.	64	Dislocation and destruction of MP joints; ulnar drift, jog of voluntary movement only	2	MP	R	Index	6
				MP	R	Long	6

* Figure in parentheses indicates number of prostheses replaced.

** Normal indicates that the roentgenogram showed no evidence of bone reaction, bone absorption, or fracture.

TABLE II

Postoperative Roentgen Findings	Range of Motion after Operation (*Degrees*)	Patient Assessment of Result	Functional Result and Remarks
Sclerosis of bone in the distal portion of prox. phalanx around neck of prosthesis	Passive 90 Active 0	"Hasn't done any good except the pain has gone"	Failure but joint retains good passive range of motion
Normal **	135–125	"About the same"	No improvement
Longitudinal fracture of prox. and mid-phalanges (Fig. 5-B)	Removed in 3 wks.	Failure	Failure (Fig. 5-A); skin slough; prosthesis removed; joint subsequently fused in functional position
Absorption and sclerosis around necks of prostheses; shift of stem within phalanx (Fig. 6-B)	170–105 170–115	Good Good	Grip, range, and strength improved; bone absorption; prosthesis settling in bone; range of motion not yet affected
Normal	170–110	Good	Great improvement
Absorption and sclerosis of mid-phalanx; rotation of mid-phalanx on prosthesis (Fig. 2-B)	175–105	Good	Great improvement
Normal	Nil	Useless	Prosthesis removed and different type substituted (see below)
Normal	175–130	"Much more use than the other joint"	Grip improved over previous state
Active disease in index, prox. phalanx	175–130	"I'm a bit better"	Pinch and grip stabilized
Absorption of metacarpal around neck of prosthesis	175–105		Range of motion not influenced by bone absorption
Normal	175–115	"Much better than other hand"	Improved over-all function particularly pinch
Normal	175–115	Great improvement	Great improvement in all forms of prehension; no interference with function despite protrusion of prong in mid. phalanx, long finger
Slight absorption about distal half of prosthesis (Figs. 7-B and 7-D)	175–110	No pain	
Normal	170–110		
Normal (Fig. 7-D)	170–130	"Better than when it was stiff"	This did not add much to function
Fracture of prox. phalanx (Fig. 8-B)	120–110	Same as before but no pain in joint	No improvement; prosthesis stable despite fracture
Normal (Fig. 9-B)	175–120	"A great improvement"	Grip restored and appearance greatly improved
Normal	175–120		
Normal	175–100	"I can hold things in one hand"	All forms of prehensile grip now possible
Normal	175–115		
Normal	175–110		
Normal	105– 95	"I'm no better"	Failure; all prostheses removed 6 mos. after insertion and joints fused in functional position
Normal	100– 95		
Normal	100– 95		
Normal; all diseased areas apparently removed	175–115	"A great help"	Pinch and grip stabilized
Normal	175–190	"Very good"	Grip improved but development of boutonnière in long finger a handicap; attempted surgical repair failed
Normal	95– 90	"No good"	
Normal	175–115	"Very good"	
Normal	175–115	"I can do much more now"	Pinch mechanism stabilized; grip improved but thumb unstable because of disease
Normal	175–110		

A pre-existing boutonnière deformity is a contra-indication to prosthetic replacement, but this deformity has also developed as a complication of prosthetic replacement of the proximal interphalangeal joint. I have had no success when repair of the extensor mechanism was attempted, either at the time of placing the prosthesis or at a subsequent operation. In neither instance was satisfactory extension obtained. In one woman, fifty years old, the central slip over the proximal phalanx was replaced by a free graft from the palmaris longus. The finger was immobilized for three weeks; the graft then worked well for three weeks, when it ruptured at its mid-point, and further repair was forbidden by the patient's sister.

In two patients, both of whom had prostheses inserted in the proximal interphalangeal joints of the index, long, and ring fingers at one time, a boutonnière deformity subsequently developed in the long finger. In neither patient had this deformity been present before surgery. In one of these patients (Case 11), an attempt was made to reconstitute the normal extensor mechanism in a second operation, but the deformity recurred within three months. The other patient, at the time of writing, still had sufficient passive movement of the joint to allow good extension if the finger was splinted with the normal adjacent digits.

Seven phalanges were fractured during insertion of the prostheses (Figs. 5-A, 5-B, 8-A, and 8-B). The one single-stemmed prosthesis that was associated with a fracture was grossly unstable and had to be removed. All other fractures occurred while two-stemmed prostheses were being impacted after insufficient reaming of the medullary canal. After these fractures, the prostheses were not found to be unstable at follow-up examination.

DISCUSSION

As knowledge was gained, the indications for prosthetic replacement became more clearly defined with resultant improvement in the results in the later cases. Despite inclusion of the early failures, the over-all results have been so encouraging that this interim report is being presented. This discussion has been limited to the possible use of prosthetic finger joints in rheumatoid arthritis. More general reviews of the whole problem of rheumatoid arthritis of the hand have been published elsewhere [2,3,4]. Rheumatoid arthritis is a continuing, progressive disease which surgery cannot cure. The use of prostheses in selected cases rapidly restores some degree of function to crippled hands. Even if this improvement proves to be short term it is of great benefit to the patient.

Patients have been operated on in all stages of the disease, except when they were in an acute generalized flare-up. In no case has the disease been activated by surgery, and it is believed that the sedimentation rate should not influence the decision to operate.

In no case has there been an untoward tissue reaction to the metallic implant. Six prostheses have been removed at various times after insertion, and biopsies of tissue adjacent to the implants have shown only minor histological reaction.

Prior to operation, many of the patients were dependent on outside help for even their most personal needs. Uniformly, they have considered their greatest gain from the operation to be the restoration of various degrees of independence. A factor of almost equal importance to the patients has been the absence of pain in the fingers containing prostheses. It has been an almost universal comment that the constant aching pain has disappeared, and that during subsequent flare-ups of the generalized disease, the pain did not reappear in the region of the prosthetic joints.

Another interesting observation is that the improvement in function of their hands has given these patients a degree of incentive far beyond that justified by

the actual functional gain. The operation causes no significant morbidity, and there has been no mortality. As a rule, the patient is required to remain in the hospital for about one week, and function is rapidly restored. Under these circumstances, it seems thoroughly reasonable to provide patients with added function, even though it may last for only short periods of time.

The long-term outlook may not be so favorable. It seems inevitable that complications will arise. Brannon pointed out that loosening or migration of the prosthesis may occur [1]. In particular, it is felt that the bone absorption which occurs around the neck of the prostheses (Figs. 6-A through 7-D) may possibly lead to obstruction of flexion if it continues to progress. In those patients in whom the two prongs have been forced together by the narrow confines of the medullary canal, it seems probable that the lateral springing force of these prongs will cause bone erosion, possibly with eventual penetration of the prong through the cortex. However, it is anticipated that the fibrous reaction around the metal will provide sufficient stability to hold the prosthesis in place. Another possible complication, with the prongs bent and under stress, is that metal fatigue may cause a fracture of the prongs at their junction with the main body of the prosthesis.

A variety of methods of treatment for the rheumatoid hand is being developed in many centers throughout the world. This work is presented as one possible procedure which has very definite limitations. It should not be thought that this paper advocates the general use of prostheses to the exclusion of such more commonly practiced operations as arthroplasty. Some of the illustrative cases have been deliberately chosen to emphasize the complications and difficulties of the procedure to try to forestall any unwarranted hopes on the part of patients or their physicians.

It is, however, hoped that this report may encourage others to repeat this work under controlled conditions in order to assess whether the procedure has a definite use in the rheumatoid hand.

SUMMARY

Metallic hinged prostheses have been used in an attempt to restore some function to the metacarpophalangeal and proximal interphalangeal joints of fingers involved by rheumatoid arthritis.

Indications for prosthetic replacement at the proximal interphalangeal joint are considered to be: (1) gross joint destruction, (2) persistent swan-neck deformity, and (3) ankylosis of the joint in a non-functional position. At the metacarpophalangeal joint the indications are considered to be: (1) gross joint destruction, (2) palmar dislocation of the joint, and (3) persistent ulnar drift combined with joint destruction or palmar dislocation. It is a prerequisite of prosthetic replacement that there be adequate muscle power to control the joint. Six cases are described and illustrated. Some typical complications, such as boutonnière deformity, fracture of the phalanges, and lack of voluntary control, are discussed.

A total of fifty-seven prostheses have been placed at the present time. A table is presented giving the pertinent information concerning thirty-one prostheses which have been in place for six months or more.

NOTE: All costs in the development and use of these prostheses have been borne by the Iowa Chapter of the Arthritis and Rheumatism Foundation.

The design of the prosthesis is based on the Brannon prosthesis. I am grateful to Mr. James Hite of the Zimmer Manufacturing Company for his invaluable technical assistance in the modification of the design of the prosthesis.

The drawing, photographs, and casts of patients' hands are the work of the Department of Medical Illustration, University of Iowa.

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DISCUSSION

Surgery of Gout of the Upper Extremity

(Continued from page 752)

Amputation of a finger because of gouty involvement is seldom necessary. Arterial circulation of a digit is not often impaired by the deposits of urates. Indeed, I have often marveled at the apparent avascularity of these fingers at the time of the operation and the prompt healing of the wounds postoperatively. When all structures in a finger are involved, however, and the useless digit is impeding function of the rest of the hand, amputation of the finger is justified, as it was in the sixty-seven-year-old man in whom the bone and the tendons of the little finger were involved.

I would like the authors to comment on the reasons why the extensor tendons are so much more often involved in gout than the flexor tendons. Is it a matter of difference in vascularity of the tendons or does the closer proximity of tendons to skin play an important role?

I also want to ask the authors what experience they have had with the preoperative or postoperative use of corticosteroids in these patients with tophaceous gout, especially those in whom there developed flare-ups of acute gouty arthritis even while taking colchicine.

I have always thought that when gout involved the hand, the systemic manifestations of the disease were quite obvious. Gout involves the hand late, not early, in the course of the disease.

Several years ago I was reviewing a series of giant-cell tumors in the hand, and, of course, I looked for these giant-cell tumors in the hand of every patient who came in. I saw one woman, sixty-five years old, who had a mass on her finger. Over a period of five years the mass gradually enlarged; every time I saw the patient I would advise excision of the tumor. She would refuse. The finger itself was never red, was never sore, and there was no joint stiffness. Some time later, she fell and broke her hip; after I had pinned the hip I advised excision of the mass on her finger, hoping to add a giant-cell tumor of the finger to my series. Two weeks before this meeting I opened the finger; much to my chagrin I had to scrape out tophaceous uric-acid deposits from the finger mass which I had been confident was a giant-cell tumor.

Conference of Heads of Departments of Orthopaedic Surgery of Medical Schools on Department-Sponsored Research Programs

FOREWORD

The Committee on the Skeletal System of the National Academy of Sciences—National Research Council is devoted to the promotion of research related to the broad field of orthopaedic surgery and as a corollary to the stimulation of young orthopaedic surgeons to engage in investigative activities. In the interest of promoting this objective, the Committee on the Skeletal System, through a grant from the National Institutes of Health, sponsored a seminar October 6 through 8, 1960, in Washington, D.C., on the subject of Mechanism of Formation of Organic Matrix with Particular Reference to the Skeletal System. Invitations for attendance were issued to the members of the Orthopaedic Research Society and the heads of departments of orthopaedic surgery of all medical schools. The department chairmen were invited to bring with them one or more of their residents and fellows who have shown an interest in investigative studies. It was the Committee's objective to bring a group of young orthopaedic surgeons with combined interests in basic science and in patients with skeletal problems into close contact with a group of outstanding investigators interested in the laboratory aspects of connective-tissue cell and matrix formation. By so doing the Committee hoped that the orthopaedic surgeons would learn methods by which their problems could be attacked and that the investigators would find potential research fellows and would learn of the growing interest of orthopaedists in basic science methods and results.

During the course of the seminar, a closed meeting of the department chairmen was held for the purpose of discussing common problems relating to department-sponsored research programs. In these proceedings there are to be found an outline of the more unfavorable factors affecting the conduct of interdepartmental research and some suggestions for the solution of these problems. In this regard, it was emphasized throughout the meeting that the character of the leadership exerted by the heads of departments is an all-important factor in determining the status of our specialty.

The conference was saddened by the tragic and untimely death of Dr. David S. Grice, Professor of Orthopaedic Surgery at the University of Pennsylvania, who was scheduled to be a participant and who died two days before the meeting in an aircraft accident in Boston. Dr. Grice, although a relatively young man, had achieved prominence in the field of academic orthopaedics and his loss to the orthopaedic world will be keenly felt by all.

It is the hope of the Committee that the publication of these condensed transactions of the meeting will be of benefit to those members of our specialty who were not privileged to be in attendance.

COMMITTEE ON THE SKELETAL SYSTEM
Dr. Alfred R. Shands, Jr., *Chairman*
Dr. D. Murray Angevine
Dr. Jerome Gross
Dr. Charles H. Herndon
Dr. George W. Hyatt
Dr. Robert D. Ray
Dr. Fred C. Reynolds
Dr. Robert A. Robinson
Dr. Harold W. Glattly, *Executive Secretary*

INTRODUCTION

BY R. KEITH CANNAN, D.SC., *Chairman*, DIVISION OF MEDICAL SCIENCES, NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

Mr. Chairman, you have invited me to open this discussion of contemporary needs and opportunities for research in orthopaedics. This I gladly do. Although I can speak with no authority in the field of your specialty, for a number of years I have been somewhat intimately involved in the administrative aspects of medical research at the national level and have watched the changing scene closely. It may be that one who looks in on academic affairs from without may see things a little differently than do you who are accustomed to look out from within.

In recent years, the word *research* has been much on the lips of those who speak to, or in behalf of, the general public. We are told that scientific research has become the major bulwark not only of national defense but of national welfare. To *do* research is to be invested with a faint odor of sanctity—to have acquired social status. The scientist welcomes this public recognition and, in particular, the largess that goes with it, but he is also a little fearful of the consequences. Let us examine the situation.

Throughout recorded history, man, as an individual, has been characterized by his curiosity about the world in which he lives. He has sought to understand it and has pursued knowledge for its own sake. Man, as a member of organized society, on the other hand, has sought knowledge and communicated it to his fellows as a way to contribute to his own well-being and to that of his fellows. This dual motivation is often described as an antithesis between basic and applied research. Unfortunately, there is seldom agreement on the definition of these terms, and discussion becomes sterile. I prefer Einstein's distinction between *science in the making*, that is to say, the search for understanding, and *science existing*, which is knowledge waiting to be put to the service of man.

Over the centuries, society has taken only a fitful interest in *science in the making*. Its attitude, on the whole, has been benevolent, and it has extended modest philanthropic support. The public has, however, regarded it as remote from the urgencies of living. It was an acceptable pastime for scholars, but it was academic and amateur. A time arrives, however, when a particular science develops a coherent group of concepts and an effective technology, constituting a substantial body of *science existing* that is ripe for exploitation. Society then begins to sit up and take notice. It recognizes a new source of power to control man's environment and to promote the good life. Promptly, society moves in on this particular science, invests heavily in its promotion, and proceeds to organize and manage it. One might refer to this as the *socialization of science*, inasmuch as society has become a partner in the enterprise. In this context it is immaterial whether the initiative be taken by private enterprise or by government.

So it was that the industrial revolution led to the socialization of the physical sciences and gave birth to the profession of engineering. In this period, the life sciences were still in the making and were left very much to their own devices. The first break came with the development of bacteriology and the recognition of a new power over the spread of infectious disease through the microbiological control of water, food, and sewage. The engineer moved in, and the art and science of sanitation became a profession. Shortly thereafter the techniques of asepsis and antisepsis, teaming up with the discoveries of anesthesia and diagnostic radiology, made possible the aggressive development of surgery. This was the first clear indication that clinical medicine was, at last, finding in the biological sciences new and powerful instruments for the diagnosis and treatment of sick people. Somewhat later, other evidence of a breakthrough came in the demonstration of the power of the sciences of nutrition and endocrinology to provide means to correct many diseases of metabolic deficiency or excess and of the power of biochemistry and hematology to sustain or replenish the circulation. However, only the unending parade of wonder drugs in the last two decades has made the layman fully conscious of the fact that clinical medicine can now be developed on a solid foundation of *science existing*.

In consequence, society is demanding more and more medical research and seems to be prepared to foot the bill. The expansion of resources for medical research in recent years has been phenomenal. The national investment is doubling every four years. It has increased tenfold since World War II, and the contribution of the Federal Government has increased fiftyfold in the same period. Today, some two-thirds of the pooled research budgets of our medical schools derive from Federal sources.

The medical scientist has welcomed this increased patronage, although he recognizes that it is placing his amateur status in jeopardy. Indeed, medical research is rapidly becoming professionalized, and our medical institutions are harboring an increasing population dedicated to research as a full-time career. A recent survey has indicated that the salaries of about 25 per cent of the full-time positions in our medical schools are provided for by Federal funds.

It is evident that the management of medical research is passing from the hands of the medical institutions in which the research is conducted into the hands of national agencies. On the whole, these agencies have administered their programs with wisdom and vision. This is notably true of the National Institutes of Health, where policies have been designed to sustain the integrity of academic institutions and the intellectual freedom of investigators. Inevitably, however, the autonomy of our institutions is diminishing, and the climate of research is changing.

Some of us may sympathize with the old-timers who lament the passing of the good old days when investigation was fancy-free, untrammeled by project applications, adjudicating committees, and the rest. It is our business, however, to learn to adapt to changing environments to preserve that which is good in the academic tradition while we accept the new responsibilities society imposes on medical science.

The first of these responsibilities is the recruitment and training of the men and women needed to carry out the expanding national effort in medical research. The Bayne-Jones Report* contains the estimate that today 8 per cent of our medical graduates become engaged in teaching and research. It may be doubted if a much larger percentage of any graduating class is suited by temperament or interest for a career involving research. In any event, it is evident that until we can materially increase the annual output of the medical schools we cannot deflect any larger proportion of young doctors to research without reducing the supply of physicians needed for the medical care of a rapidly growing population. The new schools it is proposed to establish will not relieve this pressure in the years immediately ahead. Yet the nation's advisors urge that the resources for the support of medical research should be expanded three to fourfold in the next decade.

One way out of this dilemma is to recruit more heavily from scientists who have no clinical experience. Medicine has always been alert to draw upon all disciplines that can contribute to the solutions of its problems. Today about half of those receiving grants in aid of medical research are investigators who have no medical degrees. The proportion will probably increase in the years ahead; but the supply of such talent is limited, and for it medicine must compete with industry, engineering, and agriculture.

Be that as it may, you will agree that the responsibility for leadership in medical research cannot be surrendered to the scientist in the laboratory. This is manifestly true of that area of investigation that has come to be called *clinical research*, but it should extend beyond that. The problems which we are seeking to solve and for which society is asking for answers are medical problems, and their parameters must be defined within the context of medical theory and practice. It may well be that the rate at which medical research will expand in the years ahead will be determined not by the funds available but by the supply of clinically experienced investigators with training in the basic sciences adequate to allow them to communicate confidently, both conceptually and technically, with their colleagues in the laboratory.

May I turn now to a brief consideration of the impact that the growing emphasis on research has on the total mission of a school of medicine. The role of a school is to teach as well as to investigate. The spirit of inquiry vitalizes teaching, but it can also pervert it if the balance between the particular and the general is lost. Progress in knowledge is achieved by advances in depth on narrow fronts. Specialization is essential to research, but medicine is more than a polyglot assembly of specialties. There is an intellectual unity to medical science that is the peculiar responsibility of the teacher to cultivate and to communicate. He must be a generalist as well as a specialist if the fragmented accumulations of research are to be assimilated into the corpus of medical thought and practice. The social pressures for research have led to the devising of all manner of incentives to students to undertake intensive training in narrow problem areas. There is need, in my judgment, to encourage training in breadth as well as in depth, such as will prepare a select body of men for academic leadership.

The hospitals affiliated with medical schools share with the preclinical departments responsibility for the teaching of the science and art of medicine. Beyond this, they have traditionally set the national standards of excellence in medical practice. This is because the physicians that serve them have been permeated with the academic spirit of inquiry and have so organized and so managed their services as to encourage deliberate investigation. In recent years there has been evidence of growing pressure from industry and government on university hospitals to undertake types of empirical studies that contribute little to the primary mission of these institutions. Notable amongst these are the large-scale screening programs for the evaluation of potential therapeutic agents. Insofar as these studies are logically conceived and conducted they need to be done, but this kind of manipulation of *science existing* should not usurp the primary purpose of a teaching hospital to foster *clinical science in the making*. Thought might well be given to relieving the schools of some of the burden of utilitarian investigations. It would seem that the time has come to broaden the base of operations by enlisting the more active participation of the many fine hospitals that are not presently within the academic orbit.

SURVEY OF RESEARCH ACTIVITIES SPONSORED BY THE DEPARTMENTS OF ORTHOPAEDIC SURGERY OF MEDICAL SCHOOLS

By H. W. Glatfly, M.D., *Executive Secretary*, Committee on the Skeletal System, Division of Medical Sciences, National Academy of Sciences—National Research Council

The Committee on the Skeletal System of the National Academy of Sciences—National Research Council, in an endeavor to obtain information with respect to the opportunities for research

* Final Report of the Secretary's Consultants on Medical Research and Education, Office of the Secretary of Health, Education, and Welfare, Washington 25, D. C., June 27, 1958.

TABLE I

STATISTICAL SUMMARY

Reporting heads of departments		56
Departments sponsoring research projects:		44 (80%)
1 to 3	15	
4 to 7	13	
8 to 12	10	
13 to 20	3	
More than 20	2	
Not listed	1	
Departments in which residents have an opportunity to be closely associated with research activities (6 departments have no residents)		38 (68%)
Planned research program for residents	14	
Research opportunities for selected residents	9	
Casual association with research activities	15	
Departments sponsoring research projects for medical students		22 (40%)
1 to 2	12	
3 to 5	4	
6 to 10	2	
Not listed	4	

TABLE II

Unfavorable Factors	Departments
Entire staff in private practice: teach on a voluntary basis	3
Department head only staff member on a voluntary basis	1
No residents	4
No available funds	5
No available facilities	5
Press of patient care	3
Organizational position of department	1

activities that are available today in the departments of orthopaedic surgery of medical schools, recently conducted a questionnaire survey for this purpose through the medium of the department heads. Replies were received from fifty-six of the eighty-one heads of departments to whom the forms were addressed, representing a return of 70 per cent. This sample was considered by the Committee to be adequate for the purpose of developing a statistically representative report of the present status of department-sponsored research programs and the participation of residents and medical students in these investigative activities (Table I). A majority of the reporting heads of departments included in their reports comments on factors affecting the conduct of departmental research programs and on their experiences with research activities in undergraduate and post-graduate medical education. The report presents these comments in both summary and direct-quotation form.

Department-Sponsored Research

The major feature of this survey is the wide disparity in the status of department-sponsored research reflected in the forms of the reporting heads of departments. At one extreme is a group of twelve medical schools in which the departments of orthopaedic surgery sponsor no research activity, whereas at the other there are a few institutions that have well developed and well balanced programs of both basic and clinical research projects in orthopaedics. Between these two extremes the research activities of the departments of orthopaedic surgery fall into an ascending scale beginning with programs of a token character that involve only one or two simple clinical studies. It is recognized that the position of any particular department on this scale is only generally related to the number of research projects listed in the survey forms since the character of a research activity cannot be evaluated from the title.

The basis for this disparity in the emphasis being given to investigative activities is clearly discernible in the comments of the heads of departments as to the favorable and unfavorable factors that affect the environment for orthopaedic surgeons' research programs. In this regard, the forms of the twelve departments that sponsor no research projects emphasize the major deterrents to the conduct of a research program (Table II). Nearly all of the reporting heads of departments cite one or more of the following conditions as adversely affecting research activities at the institutions:

1. *Inadequate Department Staff*

The press of administrative duties, in-patient and out-patient responsibilities, undergraduate

and graduate teaching, and training activities are such as to preclude the time for the proper supervision of a research program.

"The personnel allowance made for orthopaedic surgery permits only token research efforts by one full-time orthopaedic surgeon who must attend the training of residents and medical students and carry on an active clinical practice."

"The major deterrent to research is lack of time on the part of the faculty. Even if the faculty were subsidized to do research, there is such a demand in this community for service that I doubt if time could be taken away from service to perform effective research."

"The problem resolves itself to the necessity of having a full-time staff member devote at least half of his time to research projects."

2. *Inadequate Physical Facilities*

This factor relates to laboratory space, animal houses, and office space.

"Members of my staff are interested in conducting research programs, but there is no space available for such activities."

"The department has never had any laboratory space or animal quarters."

"All of our research must be conducted in the laboratories of other departments."

3. *Organizational Position of Departments*

Dr. William T. Green in his Presidential Address at the Annual Meeting of The American Academy of Orthopaedic Surgeons, January 28, 1957, pointed out the many problems affecting departments of orthopaedic surgery as a result of the relatively inferior status in which they are placed in the organizational framework of many medical schools. As divisions of the departments of surgery, these orthopaedic services lack autonomy in matters affecting personnel and funds. The adverse effects of this organizational arrangement were quite evident in this survey. Of special importance is the absence of a department budget, without which definitive planning on a continuing basis is not possible for a research program. The staffing inadequacies cited are a part of this general problem area.

"Orthopaedic surgery is a division of general surgery and it is entirely parasitic and without adequate budget. All administrative decisions regarding both personnel and research budget are made by the dean and head of the department of surgery with the results of their deliberations eventually reaching the orthopaedic area."

"There is a great need for department funds to initiate studies before grants are requested."

The proper setting for a well rounded research program was the subject of many comments. There is a need to have individuals representing certain of the basic sciences both to train the investigators in highly technical procedures and to participate as members of the research team. A well equipped laboratory with a full-time technician is a prerequisite to a basic research program. One department reported having the full-time services of a biochemist, a physiologist, a bacteriologist, a pathologist, and an orthopaedic surgeon whose primary interest is in research.

"Many areas of research are highly technical and demand special training in methods and techniques."

"To do research which requires the use of animals, chemical analyses, use of radioisotopes, and various types of circulatory pumps, the laboratory has to be equipped with expensive material and a technician should be available."

"I would point out the need for close liaison with basic scientists interested in matrix, mineral, and biochemical studies. Basic research is usually not productive to the orthopaedists without such close liaison."

It is encouraging that the reports of ten of the heads of departments indicate that their local situations are improving so as to permit an increase in research activities in the near future. New research facilities are under construction at certain of the institutions that will provide laboratory space for the orthopaedic service. The staffs are being augmented in a number of instances.

Resident Participation in Research

Although this item of the survey form reads "Do your residents in orthopaedic surgery have an opportunity to be closely associated with research activities?", in general, the heads of departments discussed this question from the standpoint of resident participation in research. There was general agreement that investigative activities on the part of residents were to be encouraged provided the department was in a position to sponsor research projects. Since many of the resident programs provide but one space at each level of training, the press of patient care was cited by many of the heads of departments as precluding the allocation of any appreciable portion of the residents' time to research other than clinical review type of projects. This time factor is compounded in many situations by the lack of facilities, funds, and a member of the staff to supervise the research.

The importance of motivation for investigative activities has led many heads of departments to be very selective in offering research opportunities to their residents since it is believed that the results will not be productive unless the effort is entirely voluntary on the part of the individual. A number of departments are offering support to interested residents.

"The opportunity is immense, yet it is the exceptional resident who participates in anything more basic than a clinical review type of project. Residents are largely concerned with the perfection of their own trade and should be forgiven for having more genuine interest in study for the Boards than in making some fundamental contribution to their specialty."

"Selected residents are provided with laboratory and experimental facilities with which to carry out investigations of limited scope. Certain interested and qualified individuals are awarded fellowships by the department for supervised research on an annual basis."

"Selected residents are given an opportunity to work on a research program in the laboratory for periods of six months to one year. They receive supplements from a research fellowship during this period."

In contrast to the philosophy that research should be on a voluntary basis, there were fourteen reporting heads of departments who have incorporated investigative activities into their resident training programs.

"We offer a four-year residency—the first twelve months consist of study in the basic sciences and participation in investigative orthopaedics."

"Residents are given training in methods of research. They are expected to complete a project in either basic or clinical research, which is usually done in conjunction with a member of the faculty in one of the major research programs currently under way."

"One six-month period of the residency program is devoted exclusively to a research project of the resident's own choosing. He then continues on the research project on a part-time basis throughout the remainder of his residency program."

"Each member of the house staff must initiate and complete one clinical research project during each year."

The importance of an adequate base of support in terms of facilities, trained personnel, and funds for the conduct of serious research on the part of residents and fellows is contained in the two following comments:

"If funds were readily available to support the medical student during the summer, if means were available to take the good resident out of clinical work for six months and support him while he is working on a research project, and if good young men were willing, following their residency training, to spend a major portion of a year or two in research work with some clinical work on the side, it would not be too difficult to encourage medical students and house staff to participate actively in good fundamental research programs that are within the scope of an average orthopaedic department. Our major problem is one of manpower on the senior staff for active participation and supervision in many of the problems that we might be doing but are not able to undertake at the present time."

"The final need would be for funds in the form of graduate training grants to support men after they have finished their residency training. I think these grants should have a very realistic salary allotment. It is rather absurd to offer a fully trained orthopaedic resident $6,000 to work on a research project when he can obtain $20,000 by going into clinical practice. The sooner we face this situation, the sooner we will be able to attract men to this field. The day is past when you can offer a man starvation and an academic position and make it attractive."

Participation of Medical Students in Research Activities

Although there is general agreement with respect to the value of residents engaging in investigative activities, the utility of the introduction of individuals to research during their undergraduate medical education has not been generally accepted. It is therefore interesting to note that twenty-two of the forty-four departments that sponsor research have included research projects for selected medical students. Four additional departments have plans to offer research opportunities to undergraduates in the near future. Only two heads of departments were critical of this activity.

"It is my impression that the average anatomical, physiological, and pathological education of medical students is so limited that it is a most exceptional student who would be able to carry out a reasonable research project."

"We believe it is a mistake to interfere with the procurement of basic knowledge in all fields by having the medical student engage in a research activity of a particular specialty."

It is stressed that a student-research project must be on a voluntary basis rather than *induced* by assigning students to laboratory projects for *free quarters*. When properly conducted, this program can be a most important instrument for cross-fertilization purposes by feeding back the participants into their classes who will then serve as contacts to promote interest in the field of orthopaedic surgery and in research activities. One department chairman who has successfully conducted a student-research program reports that nine students of a class of seventy-one (12 per cent) wrote their senior thesis in orthopaedics, the highest percentage of any specialty. The following quotations are typical of the experiences of the heads of departments who have sponsored research for undergraduates:

"Of the twelve most recent students who have participated in research programs, nine have subsequently pursued graduate training in orthopaedic surgery."

"Providing research opportunities for students who of their own volition apply for same is in our experience most rewarding. We have endeavored, with moderate success, to seek such students in the freshman class so that they may spend two or three summer periods with us."

"The only residents who are actually participating in basic research are those whose interest is aroused in student years. Waiting until they are residents in the specialty level and presenting them with a required research project is unlikely to bear fruit."

"Our greatest need is to interest men in the early stage of training and to guide them in obtaining basic preliminary training in preparation for the technical aspects of present-day and future orthopaedic research."

"Results have been excellent. All six undergraduates who have participated during the past three years benefited considerably and expressed the desire to engage in future research."

Summary

1. The status of research sponsored by departments of orthopaedic surgery is largely dependent upon the following conditions and factors:

A. Adequacy of the senior staff as related to the clinical undergraduate teaching, and resident training loads of the departments.

B. Provision for the compensation of members of staff to enable them to supervise research activities properly.

C. Adequacy of the essential research facilities and tools in terms of laboratories, equipment, technicians, and animal houses.

D. Availability of support from the basic science departments—anatomy, physiology, pathology, biochemistry, etc.

E. Position of the department in the organizational structure of the medical school.

F. Adequacy of financial support including a department budget.

2. Based upon the widely varying situations in terms of these factors, which exist at the institutions included in this survey, there is a marked disparity in the amount and character of the research presently being sponsored by the departments of orthopaedic surgery.

3. A satisfactory environment in which to develop the research interests of promising residents and medical students is present in the departments of orthopaedic surgery at relatively few institutions.

4. Resident participation in research is presently following two patterns in the departments included in this survey:

A. Participation of all residents in certain required investigative activities as an integral part of the resident training program.

B. Participation in research of selected individuals on a voluntary basis.

5. The participation of carefully selected medical students in research activities sponsored by departments of orthopaedic surgery appears to be in the interest of:

A. Recruitment for a career in the field of orthopaedic surgery.

B. Stimulation of the individuals for future research interests.

OBJECTIVES OF THE CONFERENCE AND RESULTS OF THE SURVEY

By Charles H. Herndon, M.D., *Chairman*, Division of Orthopaedics, School of Medicine, Western Reserve University

Although I certainly would not belittle the excellent clinical and basic research that is being pursued actively in institutions not related to medical schools, it is apparent that medical schools and their affiliated hospitals should not only have the facilities, environment, and personnel to take the lead in medical research, but should assume this responsibility. It is for that reason that the survey was directed to, and this conference is composed of, directors of orthopaedic surgery in medical schools.

It should be emphasized that, although this conference is devoted to a study of the organization of research programs, this in no way implies that research is the major responsibility of a department of orthopaedics in a medical school, but certainly it is one of the department's important responsibilities.

It is somewhat surprising that only 70 per cent of the departmental directors replied to the questionnaire. Of those who replied, 22 per cent indicated that no research programs were being carried on in their departments and another 25 per cent indicated that a program of only a token character was currently under way. One can only surmise that the percentage of departments with active programs would be even less had there been a return rate of 100 per cent. It is probable, although admittedly not necessarily so, that those interested replied, while those with little to report regarding research activities did not reply. In any event, it is an important observation that

even in this research-minded age a significant number of medical schools are for some reason not discharging the school's responsibility in the area of musculoskeletal research. It is the purpose of this conference to explore the reasons for this circumstance and to discuss ways in which obstacles may be overcome.

We are not pessimistic about the research currently being pursued, nor are we apologetic about the accomplishments in the past; but it is apparent that there is a wide variation in the manner in which different orthopaedic departments meet their responsibility in maintaining an active program of clinical and basic investigation. Some departments, working under difficulties, are unable to maintain an effective program; others operate elaborate, productive programs involving extensive laboratories and many technical assistants, residents, and medical students. Many of us would like to know how they do it. What is the difference in the organization of the two extremes? Is the development of such a program dependent upon a sound and adequate departmental endowment? Is departmental status necessary to provide the freedom required for progress? Are clinical and service responsibilities too demanding to permit time for investigative work? Are there too few orthopaedists trained in the techniques of basic research?

The difficulties most commonly reported in the replies to the questionnaire were: (1) lack of personnel trained in the techniques of basic research, (2) the press of clinical responsibilities and the lack of time on the part of department personnel, (3) lack of facilities, (4) lack of funds, and (5) difficulties engendered by the lack of autonomy or departmental status. In studying these reports, one cannot help but believe that, although all of these problems are of considerable magnitude, the one of overwhelming importance is the lack of orthopaedists trained in the techniques of basic research. Where there is a man with the interest, ability, and training, usually the other problems are overcome. It would seem that one of our major concerns, therefore, is to interest men early enough in their training so that they can and will obtain the background necessary for basic research and then to provide an environment conducive to productivity, economic security, and happiness.

Perhaps a clue is provided in the survey by the enthusiasm evidenced by some of the directors of departments regarding resident and even medical-student participation in orthopaedic research. It is undoubtedly desirable that the spark of interest should be aroused at that early period so that training and special abilities may be developed. Dr. Glattly has commented upon his impressions in this regard as he reviewed the survey results.

Another difficulty that all departmental directors experience, and one that was brought out well by the questionnaire, is the impossible task of being able to excel in all of the various categories of responsibility. The director must be an administrator, a clinician, a teacher, and an investigator. Although there are very real responsibilities in all four areas, the director usually is more interested and more adept in some areas than he is in others. Not all, and I suspect not very many of us who have the responsibility of directing departments, are trained in present-day laboratory techniques. In a number of instances, the impression was given by replies to the questionnaire that the department head, recognizing his own limitations with regard to research abilities, has concentrated upon clinical orthopaedics and has left research endeavors to investigators in other centers. One wonders if this does not lead to a void in one of the more important areas of departmental responsibility. Would it not be more productive for us to organize our departments so that those with a special talent for research can have the time and encouragement necessary to exploit it? Should it not be our responsibility to seek out men who have the interest, ability, and training and to make a place for them in our departments?

I think, therefore, it may be stated quite simply that the primary objective of this conference is to stimulate the interest of directors of medical-school departments of orthopaedic surgery to study their individual organizations and to develop aggressively within any particular structure productive programs of basic and clinical research. The secondary objective is to explore problems related to the effective establishment of such programs.

OBJECTIVES OF A DEPARTMENT OF ORTHOPAEDICS IN A MEDICAL CENTER

By William T. Green, M.D., *Chairman*, Department of Orthopaedic Surgery, Harvard University School of Medicine, Children's Hospital, and Peter Bent Brigham Hospital

The broad objective of each department of orthopaedic surgery, figuratively speaking, is to carry the banner of orthopaedic surgery with dignity, respect, and honor in the care of the patient, in teaching, and in research. In doing this, each department should create and maintain standards of accomplishment which are appropriate to the position of orthopaedic surgery as a major field of medicine. The detailed objectives of a department necessarily vary, depending upon the individual circumstances of the medical center and its environment.

Patient care: In all instances the first objective is to develop and to maintain a department with superior competence in clinical medicine and in the care of patients. Without this competence

as a beginning, other objectives are likely to fall by the wayside. The standards of medical care must pass the most stringent tests based on the results of treatment, the opinions of the patients receiving the care, and the evaluation of the medical care by other orthopaedic surgeons and by colleagues in other fields of medicine, as well as the opinions of the residents and students who are associated with the center. Unless the care it provides commands the respect of all of these, a department leaves something to be desired.

Research: Orthopaedic surgery is responsible for progress in the field of neuromusculoskeletal disease and abnormality, and each department must strive to make its fair contribution to this progress. The degree and manner in which each department contributes depends upon many factors. The contribution will necessarily be most variable; it may be in clinical investigation, it may be in basic research, it may be very limited in degree, or it may be the major activity of a department. Whatever its participation, each department must feel the need to make some contribution to orthopaedic progress. A research-minded department is a healthier department in every way.

Teaching: The third area of major responsibility is teaching. Teaching is the obligation of every department of orthopaedic surgery no matter what its circumstance. At what level the teaching is done depends upon the features peculiar to the center, but for all departments there is teaching to be done. If the center is related to a medical school, undergraduate teaching assumes a major position. Orthopaedic surgery must assume responsibility for instruction in the area of the neuromusculoskeletal system. To do this teaching in the most effective way should be the objective of every department. In every medical school the department of orthopaedic surgery should strive to obtain the necessary hours in the curriculum but, beyond all else, it should make the best possible use of the hours which it has. Adequate instruction in this field is essential to the well rounded experiences of a medical student. Teaching of the undergraduate is not only a responsibility but a privilege as well. Much of the judgment of orthopaedic surgery by our confreres in medicine arises from the impressions that they obtain in their undergraduate years. At this time, too, there is the opportunity to interest the student in orthopaedic surgery itself and to develop in him an appreciation of its importance in the total picture of medicine. It is up to each orthopaedic department to flavor its impressions well.

Teaching of our residents and graduate students is a particular obligation since they are the orthopaedists of the future and will be responsible for carrying orthopaedics to new levels. Each department should have the best possible resident-training program that it can provide. Every endeavor must be made to create an atmosphere which will attract men into orthopaedic surgery and which will provide for their healthy growth. We need to entice more men into orthopaedic surgery. Included in our plans should be the provision of better financial support for our residents and for the young man who is starting his career in academic orthopaedics.

In particular, there is a great need to attract more graduate students into academic medicine. This is one of the great needs in orthopaedic surgery. Through the activities in our departments and the opportunities in these departments, we must strive to create an atmosphere which will stimulate individuals to make this choice. One major factor that limits the number of individuals entering academic orthopaedics is, in fact, the paucity of orthopaedic surgeons in relation to the need. There are too few orthopaedic surgeons available for the many positions that are open. Men of superior capability enter orthopaedic surgery planning on an academic career. They struggle through their resident-training program of five or six years, short of funds and developing an increasing debt. They are usually married and have children. They come to the end of their years of training. They are *hungry*. Positions are open with large salaries and leading almost immediately to partnership status in practice. Their ambitions for academic medicine cool—often there is family pressure. Wives occasionally do not have the same ambitions as their husbands, and it takes a strong individual to resist these attractions and not enough do.

This is emphasized by considering the contrast between general surgery and orthopaedics. Positions for the graduating resident in general surgery are harder to come by. A desirable place may not be immediately available and, if a position is chosen, the young general surgeon often has time on his hands for some years. Research is the natural course. His chief arranges for him to stay on with a small research grant. Soon, if the individual produces, he moves on with an increasing interest in academic medicine and into a future in this field. Entering into the situation, too, is the fact that there are too few full-time positions in orthopaedic surgery and little support for men in this field.

If the primary objective of a department is to attain superior levels of performance in the areas of patient care, research, and teaching, certainly there are also many secondary considerations of vital importance. These may be emphasized by considering the findings of two recent surveys of departments of orthopaedic surgery of medical schools in the United States. Certain of these findings will be recorded here:

1. Orthopaedic surgery did not have the position in our medical schools which its importance

warrants. For the most part, it lacked departmental status. Where it was a separate department, it was almost always a minor department with little representation. Where it was a division of surgery, it was likely to have a lesser position and have inadequate representation in the decisions of the department of surgery. It was not often represented in the conclaves of the school, on the important committees, or in the making of fundamental decisions.

2. In many schools there were not enough beds for sound clinical teaching of orthopaedic surgery. The number of beds available was often dependent upon an award from other departments.

3. Orthopaedic departments, with rare exception, were not given sufficient financial support. Many had little or no budget. In 1956, the average support for orthopaedic surgery in the fifty schools with the lowest orthopaedic budget was recorded as 5 per cent of the average total surgical budget. Many schools had little or no salary for the heads of their departments or divisons of orthopaedic surgery. In many instances the chairman of orthopaedic surgery was really responsible for the support of the department or division. There were practically no tenure appointments in orthopaedic surgery with a supporting budget.

4. Orthopaedic surgery did not have a sufficient number of hours in the curriculum in most of our schools. It had no voice in determining the curriculum.

5. Most departments of orthopaedic surgery had no adequate research laboratories.

6. Finally, there were too few men entering orthopaedic surgery and, in particular, too few men entering academic orthopaedics.

All of these things require modification. The objective of our departments of orthopaedic surgery should be to correct these undesirable situations and place orthopaedic surgery in the position which it merits.

Two other responsibilities and objectives should be recorded. Each department should seek to maintain and foster the natural breadth of our specialty. It is disappointing to see that in some departments surgery alone seems to be the interest. Decreasing the breadth of our specialty will lead to a lessened basic understanding of the neuromusculoskeletal system and will tend to stifle the contributions which our specialty should make. For many reasons it would be better to think of our specialty as orthopaedics rather than orthopaedic surgery. Finally, orthopaedic departments should be sure that orthopaedic surgery meets its responsibilities to society. In earlier days orthopaedic surgery was a leader in the public health measures concerned with the handicapped individual, rehabilitation, and related activities. We need to re-affirm this position and to inculcate in our residents the knowledge and the spirit to meet and assume this position.

Orthopaedic surgery is a major area of medicine that has many privileges and responsibilities. Let each department give thought to the effectiveness with which it discharges its responsibilities.

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DISCUSSION

By Charles E. Gregory, M.D., *Chairman*, Department of Orthopaedic Surgery, Southwestern Medical School, University of Texas

Dr. Cannan, in his opening remarks, mentioned that some two-thirds of the research in this country is underwritten by the Federal Government. He pointed out some of the problems that might possibly arise from this kind of arrangement. I would like to bring up the question, however, of how much of this two-thirds of the underwriting carried on by the Federal Government is actually diverted to help support various departments and services *in lieu* of *hard-cash* money which does not have to be accounted for in the same fashion as research money. What influence will this increasing Federal support eventually have on the various departments which necessarily (now and in the future) will become engaged in research? One might wonder whether research will be oriented to the departments of orthopaedics in the various institutions, or whether the performances of the departments of orthopaedics will be oriented to research. This, I think, poses something of a problem that might be reflected upon by all of us.

It has been said that good teaching is the by-product of good research. While this is probably true, we must recognize that good research and bad research, for that matter, produce a mass of material which has to be sorted. That which is good should be kept, but it has to find its way into an already overcrowded curriculum which is trying to fulfill its obligations, using the allotted time assigned to each of the various departments in the medical schools. This means that departments of orthopaedics must be extremely careful in selecting the material which they present, and it also suggests to me that if we must do research it might be well to do some research on the effectiveness of our present teaching methods. Surely, there are some techniques that are superior to others.

By such study we might better select the material we will present to the students. It is without question necessary to do so if we are to bring an adequate number of medical students of the right caliber into orthopaedic surgery. One has only to reflect briefly on the number of applicants for medical schools today—as compared to ten or fifteen years ago—to realize, indeed, that we are competing, and not too effectively, for the young manpower of the nation. This makes its way down to the narrow specialty of orthopaedic surgery. It means that we are soliciting ever larger numbers of trainees from a continually contracting reservoir of high-caliber students.

I might then pass on to one question that Dr. Green raised. That is the question of the stature of the orthopaedic department or division in a medical school. It is my impression that departments really and finally are comprised of people. They are made up of men, and that is the way they will be measured. If the individual at the head of a department has stature, his department will have equal stature in the functions of his school and in the considerations of the various problems presented to its councils. If the man is the chairman of a division, his division will have stature only insofar as he has stature.

Furthermore, the implements that are necessary to the effective conduct of the business of the department—by which I mean space in the curriculum, number of hospital beds, and square footage of laboratory space for research—will by and large be determined by the stature of the department, which is the stature of the chairman of the department.

ORGANIZATION OF A DEPARTMENTAL RESEARCH PROGRAM

By Fred C. Reynolds, M.D., *Chairman*, Department of Orthopaedic Surgery, Washington University School of Medicine, St. Louis

I have been asked to open the discussion on the organization of a departmental research program, not because I have any special qualifications in this field, but probably because I have been struggling with this problem for a number of years and still have a long way to go. I was grateful to have received a copy of the results of the questionnaire that Dr. Herndon sent to each school. Study of the finding in this survey reveals that my own problems are shared by most of you here. since matters of time, money, and space continually recur. I feel sure that if we had plenty of time, plenty of money, and plenty of space, a great deal more research would be carried on in our various departments, but seldom is this ideal obtained and even more rarely is it available at the outset.

Time, money, and space are, then, real problems to most of us. Particularly is this true in orthopaedic departments that are a part of general surgery. Although these obstacles are formidable, they are not in fact insurmountable, nor are they the most important for the development and conduct of research activities. For if the will is there, gradually a way will develop. We have always been faced with inadequate space, a shortage of time, and little money. True, we have not contributed a great deal, but I feel that we are growing. We have in the past, and we continue to combat these problems in a number of ways.

First. one must have an idea or an unknown that he wishes to explore. Although I have never accused myself of having had an original idea, in everyday teaching so many unknowns are apparent that it is not difficult to come upon a problem. In developing a research program, one of the real difficulties that immediately becomes apparent, in my case at least and perhaps for some of you, is that we are inadequately trained, not only in basic knowledge but also in the methodology of modern research tools; that during the time that we have been becoming proficient clinicians, the rapid advance of scientific information has passed us by. Faced with this very unpleasant fact, should we throw up our hands, give up on research, and take the attitude of let the other fellow do it? I say no, not at all, for there is more than one road over the hill. Realizing our inadequacies, then, how can we get this program off the ground? It is my firm conviction that to solve the problem of time, space, and money it is necessary to make a start, no matter how small, but at least a start. At the outset we will work in inadequate quarters, with poor tools, and often with sick animals. This is a discouraging way to conduct a research project, but it makes a start. As we all know, once a project has started, ideas become unlimited; and the work is expanded into areas that were not originally anticipated. As a result of this effort, the school is aware that research is being done, and as time goes on it is much easier to obtain space.

What about money? Like space, there is never enough; but also like space, it can be found; and as work progresses it seems to be more readily available. The important thing is that the work be begun and that it be continued; money and space then tend to fall in line, and, although never adequate, do continue to expand as the work expands.

But what of time? If time is devoted to research, teaching and clinical practice must suffer; it is seldom possible to be engaged actively in the practice of medicine, to carry on a heavy teaching program, to spend an adequate time carrying out research activities, and at the same time to live something that resembles a normal life or spend any time with our families. Teaching and the render-

ing of patient service are so intimately related that a teacher, even a full-time teacher, cannot do a first-class job of teaching unless he also practices. The answer to time, then, must be increased efficiency, together with a decrease in time spent in recreational and family activities. Teaching and practice activities must almost of necessity be restricted to a single institution, but even in these circumstances the added administrative responsibilities for the head of the department may well keep him out of the laboratory, except in a supervisory capacity, even with the most efficient setup.

The problem of time, then, must be solved by more efficient operation and a longer working day. But more important than time, money, and space, is the development of the proper environment for investigative activity. People cannot be forced, nor can they long be bought, to do research; they must be led. My concept, then, of the organization of a departmental-research program is that the head of the department must be able to attract young men into the teaching program, then by daily contacts in this program to stimulate them to seek by laboratory investigation the answers to the many problems which constantly present themselves, and to make available to these young men the space, the time, and the money required for this work.

These things can be done; but no individual, no matter how dedicated, can carry on his best and most creative work in an unhappy and dissatisfying environment. Although by hard work we are able to create something of an academic atmosphere, to provide something in the way of space, time, and money for research activities, one wonders how long society can expect these highly trained and capable young men to continue to perform these functions at a wage scale comparable to that of unskilled labor.

DISCUSSION

By I. V. Ponseti, M.D., Department of Orthopaedic Surgery, School of Medicine, University of Iowa

The Department of Orthopaedic Surgery of the State University of Iowa was organized in 1915 by Dr. Arthur Steindler as an autonomous department with 120 beds: it has always had its own budget. A laboratory of bone pathology was established in the early thirties by Dr. Ernest Freund, and it has been enlarged throughout the years by staff members interested in bone pathology. Important specimens and a collection of slides are housed in the laboratory. A biochemistry laboratory has been organized in the past ten years and is now fairly well equipped for research with one full-time biochemist. We have access to excellent animal quarters which house all the animals for the medical school and which is under the supervision of a full-time veterinarian. We enjoy close collaboration with the Departments of Pathology, Bacteriology, Organic Chemistry, Zoology, Physiology, and Radiation Research.

The entire faculty of the medical school has been full-time since 1947, and we all have a salary ceiling. The income above the ceiling is used by the different departments and the medical school to support early phases of research done by the faculty, as well as by students during the summer. Under the direction of Dr. Carroll B. Larson, the department is organized in a democratic manner. Each of the staff members is free to develop his own ideas in either clinical or laboratory work. At a daily one-hour meeting with the staff and residents, cases of special interest are presented, and two weekly seminars are held on basic sciences connected with our specialty. We try to spend at least one day each week in the research laboratories. Our limitations in research are mostly due to our own deficient preparations in modern techniques. It is often easy to carry on the first stages in a research problem, but difficulties very often arise as the experiment progresses. Our research projects are often sufficiently supported by Federal grants.

It seems to us that there is a need for well trained orthopaedic surgeons in basic research. This could probably be solved by early training, beginning in the last years of medical school and extending up to a Ph.D. in biochemistry, anatomy, or biophysics, for example. Then an orthopaedic residency for this well grounded man would have much wider horizons. The men should be chosen for their capabilities and desires to work in basic problems; support for them must be available in the form of scholarships which would provide sufficient income for prolonged training. Federal support could be available for this. At the present time, we have one of our residents taking a Ph.D. in biochemistry, but he is supported by the local chapter of the American Rheumatism Foundation. Scholarships are a necessity to provide for young men the necessary training in the basic sciences related to orthopaedic surgery, in order that these men will be properly equipped to carry on research and to enhance the future of our specialty.

COMMON PROBLEMS IN THE ORGANIZATION OF RESEARCH PROGRAMS

By Frank E. Stinchfield, M.D., *Chairman*, Department of Orthopaedics, College of Physicians and Surgeons, Columbia University

I am sure that we have all been confronted with similar problems in the organization of a

research program in orthopaedics. Consequently, what I have to say here will not be entirely new; but, for the purpose of discussion, we may identify at least five distinct areas: cooperation and understanding, space, financing, personnel, and teaching.

Until recently, research in orthopaedic surgery was limited to three fields—clinical research, perfection of techniques, and use of mechanical apparatus. With our entrance into the more basic type of research, such as biochemistry and tissue culture, we have moved into fields previously occupied by the chemist, the medical investigator, the endocrinologist, and the pure scientist. Only then did we gain our rightful place in the total picture. By so doing, however, we frequently trod on the toes of other specialties. Not infrequently other departments felt that a department of orthopaedic surgery was not prepared to do basic research—not infrequently they were right. Only through cooperation and understanding among all departments was it possible to beg, borrow, and steal equipment, personnel, and space enough to get a foothold. Thus, at the very outset, we must acknowledge that much of our present success is due, in a large part, to the cooperation and understanding of other departments which have a much greater tradition of research.

The second problem concerns necessary space. In most instances, adequate space for orthopaedic research has been provided. This seems to be true whether it is applied or basic research, or whether the specialty is a departmental unit or under general surgery. Generally, the larger facilities are those in which basic programs are in progress. In my experience, I believe that expanded research programs can be justified if the significance of results is basic enough to cut across specialty boundaries. As an example of what I mean here, I might mention the studies in my department many of which, while of primary interest to orthopaedic surgery, have implications in the fields of arthritis, connective-tissue disease, endocrinology, nutrition, and cancer. Where there is adequate motivation there seems to be adequate space at the moment. Expansion of current facilities must, however, be planned in institutions with long-range investigative programs.

The third problem has to do with financing. Here the most important consideration is the need for long-term support. Only in this way can we provide continuity of effort and some measure of security for technical employees and relieve the investigators from the burden of multiple research proposals and progress reports. Much of the research done in this country is supported by two or more sources. Think of the duplication of fund-raising effort, bookkeeping, and *grantsmanship* engendered by such a system. Despite the vested interests of the *voluntary* foundations and their desire not to put all their research publicity in one basket, there must be a more efficient way. When more groups follow the lead of the Heart Foundation and the Cancer Foundation in establishing life-long investigatorships, a step in the right direction will have been made.

This brings me to the other point of major importance—the need for money to support principal investigators. Most agencies will pay for technicians, secretaries, and assistants for everybody except the most important individual, the principal investigator. It is not difficult to understand why so few institutions can establish a full-time orthopaedic research department. It is because of the difficulty in acquiring sufficient funds to pay the principal investigator. Few men of independent financial means can and want to do research in our specialty. How many men, even though qualified, will after long resident training, and with families, consider a full-time position at $8,000 to $10,000 a year, when after a few years of practice they can be making two to ten times as much in a society that frequently uses a monetary yardstick for measuring the worth of a man? Only a handful of the more resolute and dedicated individuals will accept positions under such circumstances. I do not believe it is enough to organize orthopaedic research programs solely around underpaid basic scientists. Regardless of the worth of the contributions, there are few who have enough background to understand either the clinical problems or the clinical significance of their results. Therefore, it is essential to have orthopaedic surgeons who can translate basic findings into practical applications. To attract and hold these men there must be a more realistic financial reward than is generally available today.

One final point on financing has to do with the matter of major equipment. Few agencies will allow funds to be used to purchase items such as the automatic beta-gamma scintillation counter. The United States Public Health Service would buy electron microscopes in years past, when they were being used largely to investigate electronmicroscopy as a technique. Now they are commonplace, and the individual laboratory is left to its own devices to raise funds for such an item. As engineering and electronic know-how is expanded to provide even more complex and expensive instruments, the question naturally arises, who will bear the cost? Unfortunately, some men in the fund-raising world take the position that many of the new apparatus only confuse the total picture. To these individuals more and more equipment means fewer results. In some instances their position may be justified, but it would be unfortunate indeed if this sort of approach became universal.

The fourth problem that should be discussed is that of personnel. In order to develop principal investigators, we must be ever vigilant for the inquiring mind. Preferably, it should be recognized and stimulated in medical school and then guided along a path of training which will lead it to a

productive career, spanning the gap between basic research and clinical need. This is the primary personnel problem, for in its solution lies the hope for productive basic science and clinical research teams. Technical help in all forms is but a minor problem.

I might say here that I do not feel that every resident or attending physician should either be asked or be required to do basic research, although I do feel that all should be required to do clinical research. In our orthopaedic-training residency, we make available to all of our residents the opportunity to do basic research but we find that a very small percentage are receptive to such opportunities. Most of them wish to do clinical research only.

The last of my five points has to do with teaching, and this is divided into two parts. The first involves the relationship between research programs and orthopaedic surgeons in training. I am not convinced at the moment that there is much value in a research background for all. Certainly it does not seem wise to dabble in research, and to do more than this requires considerable time, usually at least one year. This does not mean there is not a place for a well conceived, short-term project that uses familiar techniques and has a limited objective. It does mean, however, that we should be able to provide adequate time in a training program for any gifted, serious surgeon who wishes to acquire the necessary fundamental research techniques and philosophy. This will require time in addition to the regular residency. In some institutions the added year or two may be used by the individual to obtain an advanced degree such as M.S. or Ph.D.

The second part of the teaching problem has to do with training Ph.D. candidates in physiology, anatomy, or biochemistry in research laboratories where a broad perspective can be gained. For instance, a man working for his degree under a research biochemist in the orthopaedic-research laboratory is potentially more valuable to orthopaedics than is a man who gets his degree separated from all association with the orthopaedic biochemist. The man working in the orthopaedic laboratory learns biochemistry and radioisotopes as tools while being exposed to a background of bone as a tissue and as a clinical problem.

In summary, I feel that a research program in a teaching institution is a direct reflection of the caliber of the principal investigators and the amount of blood, toil, tears, and sweat which have been put into it by the chief of the orthopaedic department.

DISCUSSION

By James S. Miles, M.D., Department of Orthopaedic Surgery, School of Medicine, University of Colorado

It would be easy to stand here and reiterate the major problems that the previous speakers mentioned, but instead I shall confine myself to some of the minor problems in establishing a research program in orthopaedics. My comments shall be based on personnel and personal problems. One must state that a tremendous amount of red tape has come up with regard to research projects. In many instances, the director finds himself merely an executive filling out papers and forms applying for research grants, training grants, and so on. I wish there were some way to decrease this burden, but apparently there is none. It has produced a new breed of cat, which we call the *gamesmanship cat*. In our institution, a sad example of this came up recently. We do not have a standing promotions committee, but have *ad hoc* committees to consider promotions. I was fortunate enough to be sitting on one of these committees regarding the promotion of a member of another department. The departmental head presented to us a statement about the value of this man to his department, but he seemed rather lukewarm in his praise of the man. Finally, he came to the clinching argument when he said that this man really did not help very much in the teaching nor did he help in patient care, but his real value was in writing up research grants. It is a sad thing when promotion from assistant to associate professor is dependent upon whether or not a man may write a good research request.

Research falls into many categories and a decision must be made as to who should be included —attending men, residents, and students. One must also determine whether the inclusion of residents in the program is voluntary or required. In our institution, we decided that this should be a required part of the residency. We set apart a six-month period in which the resident does nothing but research. He may do whatever he wishes, either basic or clinical research, but he must plan and carry out his own project. Direction is then very difficult. In some instances, the resident will have big ideas to solve the problem of cancer in six months. In other instances, the resident has no idea of organization whatsoever. It is our thought that this is good training nevertheless because for the rest of his life the physician will evaluate the research projects of others. We think it is wise for him to know the problems involved in setting up a project. A decision must be made whether this research period should be early or late in the residency program. We have arbitrarily chosen the third year of a four-year program. It is our feeling that, if we pushed the resident into research in the first year of his program, he would be nothing but a drone performing services for the principal investi-

gator. He would not know the clinical significance of the research he was undertaking, nor could he be expected to contribute any ideas to the project. It is also our feeling that, if we left the research until the fourth year of resident training, the man would not have time to continue it should conditions arise which would prolong the project.

Finally, I would like to add one comment which has not yet been made. This is a rather personal comment, and perhaps rather more a confession than a valid comment in a meeting such as this. In many instances, I suddenly get an idea or listen to the idea of another eager young investigator. The next step, of course, is to determine what has been done in this field. Often I find that such ideas and projects have been proposed and worked out some time ago. Perhaps I have some minor little variation, or perhaps the young investigator has a slightly different approach. I must then decide whether I should continue in the project or drop it. In addition, if it is a young investigator asking me for advice, I must find means of discouraging him from entering this project without discouraging him from performing research. This is a very difficult task. However, it is a task which must be performed, because too often I see *research* presented which is merely a repetition of well known data. I am merely emphasizing the importance and responsibility of the principal investigator and his advisor. The direction and stimulation of research is a difficult problem for me personally.

IDEAL PREPARATION FOR ACADEMIC ORTHOPAEDICS

By Robert A. Robinson, M.D., *Chairman*, Department of Orthopaedics, School of Medicine, Johns Hopkins University

To discuss the topic of "ideal preparation for academic orthopaedics" is indeed quite an assignment. To do so with any validity, we must, I think, define the criteria for someone in an academic position. To begin, I would point out four things: first, I think that integrity—that is, mental honesty—is a foremost requirement; second, the person should have an extensive, coordinated, and up-to-date practical knowledge of his field—in other words, any person in academic orthopaedics ought to be a first-class orthopaedic surgeon; third, he has to be one who seeks the answers to unsolved problems, not just someone who asks questions. We must set limits here. What is needed is the ability to think logically and reasonably, to evaluate not only evidence self-obtained, but also evidence available from other people, to pose well defined questions, and to arrange investigations that will give relevant answers to these questions. Whether the research be in chemistry, in physics, or at the bedside, all I say is that the questions posed should be definite and that the experiments should be well organized and designed to answer questions. Fourth, an academic person is one who yearns to teach—to study and to write down the findings of his investigations.

Environment is of the essence. What factors in some environments produce those who have academic leanings and develop these leanings in others? I think the first point is close contact between teachers and students. Second is the availability of both the intellectual and physical tools with which to attack problems that provoke the person's interest. Third, there is an atmosphere in which there is respect for well considered ideas, even though they are new, and the moral, physical, and financial support to test such ideas.

In general, one does not make academicians out of whole cloth. In orthopaedic surgery, certainly, one carefully observes the medical students, interns, and residents, and picks out those who have an academic leaning. It is true, of course, that the environment, or at least certain people in the environment, may have by their example and interest developed such academic tendencies in the individuals selected. But when a student shows such tendencies, they have to be nurtured. To do this, a teacher must have time to talk to the student, to expend energy in helping him, and there must be placed at the student's disposal the tools necessary for him to achieve answers to questions. Thus, the environment must be such that time is available for teachers to develop students with academic yearnings. Funds are needed to provide this time and to supply the tools to be used in finding answers to problems that interest the student.

How are these requirements best met? I think that there should be some variability in resident training for talented individuals. Residents should have a very complete clinical training, but I think that it should be possible to alter sequences in the training program, perhaps extending it if necessary. Here again funds must be available to accomplish this. If a resident comes along with these leanings, then perhaps in the second year of a three-year program, or in the third year of a four-year program, he should be taken out of the usual resident-training program and given a course in which he develops the tools with which to find the answers he is seeking. If you wait until after the resident training, the fellow may branch off from orthopaedic surgery completely and take a Ph.D. in biochemistry or biophysics. A lot depends on what kind of a man he is. If he feels that there is one field in which he must have the special tools with which to solve his problem, then I

suppose he should get a Ph.D. However, the disadvantage of obtaining this degree is that he loses contact with orthopaedic surgery for a considerable period. Oftentimes, I think, if the individual is intelligent and he is supported so that he can get away from the demands of his practice whenever it is necessary, he can gain the tools that he needs along the way over a period of years. I believe that the university should be in a position to support gifted individuals in this manner, allowing these men time to pick up the knowledge and techniques as they are needed.

What is the ideal training for academic orthopaedics? The environment must be correct for the particular student. I do not think there are any hard and fast rules or requirements that can or should be laid down. In general, the training program should be longer, broader, and, in some areas at least, more complete than for those interested solely in the practice of orthopaedic surgery.

METHODS OF STIMULATING INTEREST IN ACADEMIC ORTHOPAEDICS

By Crawford J. Campbell, M.D., Medical College of Union University, Albany

There has emerged a trend in which the majority of full-time department heads are responsible for all aspects of orthopaedic surgery in our medical centers. This trend has been highlighted by our meeting today. The problem of supplying from our training programs an adequate number of good candidates for academic positions is evident. The background requirements for these academic positions include a superior level of clinical competence and many special qualifications and experiences which are vital. Departments of orthopaedic surgery must not only care for patients but also teach the proper subject material to students and residents. The curriculum must include experience in basic science investigation. It is doubtful if the resident today, trained in a conventional program, can be expected to master the methodology of research or the discipline required of the curious scientific worker. The best opportunity to acquire these skills and training in investigative work would appear to be during the predoctoral years. This would be a sizable, time-consuming, and important commitment of time. Two years of research experience, concurrent with other educational experience, would be the minimum time required for such an indoctrination, in my opinion. Such medical-student activities in research would enrich the capabilities of these men for productive study during their resident years; it would also produce more orthopaedists who have the potentialities for academic life. Unquestionably, there are additional attributes such as proper motivation to serve others, the desire to make a significant contribution to science, and the ability to communicate ideas and to teach, all of which the academician must have in order to be successful. We as teachers must be on the lookout for these qualities in the students and residents, and we must make every effort to recruit superior men of this type in order to ensure the propagation of our specialty.

We are all charged with the responsibility of assessing our own programs and considering their strengths and weaknesses. There will be little difficulty encountered in the recruitment of the best candidates for academic positions in coming years if we establish adequate programs which are designed to provide proper career preparation. On the other hand, it is quite likely that we will be disappointed if we follow the traditional pattern and merely watch for a superior resident to come along and then offer him a position on the full-time staff on a trial basis. The augmented medical school program envisaged here will probably require our training services to become larger and better staffed. There is little likelihood of producing too many candidates for academic orthopaedic surgery and there is no doubt that the enrichment of our teaching efforts, particularly in basic science and research, will increase our contributions to the total teaching programs of our own institutions.

DISCUSSION

By J. William Hillman, M.D., *Chairman*, Department of Orthopaedics, School of Medicine, Vanderbilt University

The problem before us—methods of stimulating interest in academic orthopaedics—implies by its title that there is a need for concern over the proper preparation of a sufficient number of men to fill the necessary positions in teaching institutions. While orthopaedic surgery has been growing in size as a specialty, there has also been a concurrent centrifugal growth in the number of areas which we would like to consider as a part of our domain. With the passing of the "plaster, strap, and buckle" era and the assumption of a major role in the field of surgery, we find ourselves faced with widely dispersed problems including the care of children and adults, rehabilitation, forensic medicine, and many other areas of medical-social significance. In addition, there has been a remarkable growth of clinical and basic research programs. For those who work within an academic setting, the time and effort required to fulfill administrative responsibilities have increased, and the frustrations resulting from unsatisfactory arrangements for teaching students are well known.

From one medical center to another, there is a considerable difference in the areas of orthopaedic responsibility, and in many instances it would appear that expediency has become more of a determinant than conviction.

Within this poorly defined framework, we must consider the proper steps to ensure the procurement and development of personnel for our teaching areas. It is not possible, nor would it be desirable, to plan that all future academicians be uniformly prepared for each of these varied responsibilities. The minimum core of experience should include the development of clinical skill and competence, an opportunity to assume graduated responsibility in the discipline of research, and a measure of practical experience in teaching.

To enhance further the attractiveness of teaching and of academic life, it will be necessary to clarify the status of orthopaedic surgery as it relates to the parent department of surgery and to the teaching center as a whole. Adequate financing in the future promises to be even more difficult than it is at present if orthopaedic surgery accepts an enlarged responsibility for more adequate career-oriented training of residents and students. We must be mindful, however, that the more any division of orthopaedic surgery insists upon severance the more will be its responsibility for self-care. Independence of a specialty service is not necessarily synonymous with effectiveness. We must be on guard, moreover, not to direct our efforts entirely toward self-propagation at the expense of top-level teaching of students and residents from other specialties.

Teachers of orthopaedic surgery are responsible for the recruitment and training of the men who will come into academic positions. We must define our objectives, clarify our administrative channels, and make specific plans for the proper maturation of the men who can fill these positions. We must have an active student-teaching program, and the student who becomes interested must have an opportunity to participate in the clinical and research activities of the department. We must modify our training plans to permit the superior resident to gain particular background and skills which would make the peculiar demands of academic orthopaedic surgery more attractive and less threatening. We can make the future development of our specialty secure by concerted efforts along these lines.

DISCUSSION

By Don H. O'Donoghue, M.D., *Chairman*, Department of Orthopaedics, School of Medicine, University of Oklahoma

I belong to that vanishing breed that Dr. Crawford Campbell mentioned a little while ago, namely, the part-time orthopaedic-department chairman. I mention this in order to give you some background for the few words I would like to say.

I believe that we are developing an obsession about the question of *full-time* as opposed to *part-time* staff. It is all relative in any event. Many of our so-called *full-time* men spend less time lecturing at the medical school or teaching the residents than do the men who are called *part-time*. I do not think that necessarily you must have full-time men in order to operate a successful program. Until a few years ago at the University of Oklahoma, we had no full-time clinical professors. Now we, too, are undergoing the metamorphosis which is taking place in all the medical schools of the country; we now have full-time professors in the so-called major departments, namely, surgery, pediatrics, medicine, obstetrics and gynecology, and psychiatry.

This change, I believe is a good thing. I happen to be Chairman of the Faculty and have cooperated with the administration in implementing the change in the faculty to a combination of full-time and part-time professors. We are doing our best to create an atmosphere where the full-time and the part-time men can work together. However, I am chagrined to discover that all too frequently the arrival of a full-time department head, particularly if he is an energetic, earnest, and worth-while person, means the gradual departure of the part-time teacher. I have seen this happen in many departments in our school. The arrival of the full-time department head is almost inevitably the signal for the arrival of several other full-time men, usually supported by research grants of some sort. With these additions, the full-time men are able to carry out all the teaching and, indeed, all the clinical work. In other words, they can get along without the part-time men. Very often the assignments given the part-time men are such that it is difficult for them to fit them into their busy schedule of private practice. The result is that the part-time man gradually abdicates his responsibilities and the full-time man eagerly accepts them.

Dr. Reynolds mentioned that he has added three full-time men to his department. I dare say that little of the teaching is now done by the men in private practice. You may say that teaching and clinical practice are not related to research, but I believe they are. Actually, some of the most important strides in orthopaedics have been made by men doing clinical research. It is not the man who sits down and tries to think up something to investigate who is productive but it is the man who, in the course of his busy practice, has found a problem which he has not been able to solve.

So what does he do? He "goes to the dogs". By this I mean that he goes to animal research in an effort to seek the solution to his particular problem. The best research arises in the solution of a problem which presents itself.

I feel quite free to disagree with Dr. Reynolds, and also with Dr. Gregory, in this respect, since I agree with them 99 per cent of the time. It is my conviction that you must have an active practice *in* order to teach clinical medicine. This reminds me of a young orthopaedist who said that he did not care to have a big practice because he wanted to have time to write. The question of what he was going to write about had not occurred to him. All the speakers have agreed that to carry out successful research you should be a teacher. They also agree that you should be a practitioner. It has been said, however, we need men added to our departments to carry out research, since the other men in the department do not have time. I submit that these men, who are our teachers, are better able to carry out research than someone who is not busy.

I think it is an oversimplification of the problem of research simply to hire a man to carry out research. The successful research project must arise from the necessities and vicissitudes of orthopaedic practice.

DISCUSSION

By F. P. Dewar, M.D., *Chairman*, Department of Orthopaedics, School of Medicine, University of Toronto

At the University of Toronto, the Department of Orthopaedics is very loosely organized, with divisions in five hospitals under the over-all direction of the professor of surgery. I happen to be the Chairman of the committee that advises the professor with regard to orthopaedic training of graduates and undergraduates. The staffs of the teaching hospitals are made up of University appointees who receive a small honorarium from the University, but who essentially serve voluntarily. Orthopaedics is just now attaining its majority in Toronto.

One could hardly listen this morning and not be impressed with the necessity of educating the educators. Many of us, since the war, have been overwhelmed by the tremendous advances in technology that have become available to medical research. We have not all had the opportunity to become familiar with these methods. The first thing that I would suggest is that a conference such as this, devoted to new developments in the study of collagen and intercellular substances, and perhaps at some future date to immunology, be repeated annually for our edification. Although the details of these matters will appeal more to the younger man, more actively engaged in research, than to the heads of departments, nevertheless I beg for the senior the privilege of attending.

In Toronto there is an increasing interest in both clinical and basic research. Clinical research is expanding with the development of a system of fellowships for postgraduate students, many of whom are engaged in studies necessary to obtain higher degrees and who wish a period of time free from the tasks of resident training but at the same time linked to the activities of an orthopaedic service.

We have always had at our disposal a small animal laboratory where we could take our clinical problems. Three of the University's staff physicians are actively engaged in directing research projects in the laboratory and are assisted by three postgraduate students. Easy consultation is available with all other departments of the faculty, and much assistance can be obtained in this fashion. However, as orthopaedic surgeons, we have not tackled what might be called a giant basic research program such as we heard of this morning. We must wait until we can obtain the service of someone who is well trained and knowledgeable in the necessary techniques, and who will remain as a full-time research worker and director of our laboratory.

One thing not as yet mentioned that has been valuable to our orthopaedic service is the maintenance of close relationships with the Department of Medicine, particularly the rheumatologist, and with the Department of Pathology, with whom we hold frequent common rounds. On occasions, our postgraduate students are employed in the Department of Anatomy and Physiology, and more recently we have found a new ally in the Veterinary College associated with the University.

DISCUSSION

By Jack Wickstrom, M.D., *Chairman*, Department of Orthopaedic Surgery, School of Medicine, Tulane University

I wish to emphasize the importance of promoting orthopaedics through teaching and research in order to extend its influence and regain its position in extracurricular circles, as well as in school programs. I have been most distressed by the inroads which have been made in volunteer health

organizations and in national committees, as well as in government agencies, by other disciplines in medicine that tend to relegate the orthopaedic surgeon to a mere technician working at their direction. I am especially alarmed by the attitude exhibited by persons in charge of these agencies and volunteer groups toward orthopaedic surgeons in general. I believe the recognition of this aspect of our over-all problem is as important as developing extensive research programs. Actually, the aspect of this matter that most concerns me is not the aggressive attitude of the opposing disciplines as much as the lack of interest exhibited by many of the orthopaedic surgeons. It is my opinion that we have created a void or vacuum which has allowed individuals less qualified to take over large segments of patient care which were formerly the primary concern of the orthopaedist. I believe that we must, as a group, take cognizance of the importance of this trend and do everything within our power to counteract it. I believe that this is the task that faces the head of every department and every organization in orthopaedic surgery and presents a challenge we cannot ignore.

TRAINING GRANTS PROGRAM OF THE NATIONAL INSTITUTES OF HEALTH

By Frederick L. Stone, Assistant Chief, Division of General Medical Sciences, National Institutes of Health

I am very happy to be here this evening to talk to you concerning this subject which of late has taken on importance and significance in medical education and training. In the first place, I would like to expand the subject to include a discussion of the possible sources of support for training through the various extramural grants and award programs of the National Institutes of Health.

It occurs to me that far greater use could be made of the research-grant mechanism in providing support for a young man who is undergoing clinical training in orthopaedic surgery. May I clarify this. A research grant may be awarded in order to provide support for professional personnel as well as for technical or administrative personnel who are working upon a particular research project and research program.

In addition to the sums needed for professional and supporting personnel, funds may be requested for equipment, supplies, and other necessary expenses, including in certain special cases the necessary research costs connected with the care of the patient in the research situation. Many times, one member of the professional team is a young man undergoing clinical training in an appropriate specialty. This method of support for residents could be much more often employed than it has been in the past. It requires some flexibility in the resident-training program within the institution. The appointment of the young man, however, as well as his salary, is a matter at the discretion of the Chief of Service and the institution concerned. While the young man is employed on a research grant and thus receiving stipend support, it may be necessary in some cases to extend the total amount of time during which he is getting his clinical training. The additional advantage of inclusive research experience, however, is thought by most scientists and physicians to be clearly in the interest of the young man and will make him a better practitioner, whether or not he undertakes a full-time or part-time research career thereafter.

All of you here tonight should feel completely free to request advice from any of the staff at the National Institutes of Health concerning the interpretation of policies and procedures which may permit the support of young men during the time that they are in a training status.

It should be made clear that the purpose of the Research Training Grant Program is to provide funds to public and private non-profit institutions, such as the medical schools, for the establishment or improvement of graduate research training. The purpose of the Program is to increase the number of highly-trained scientists in investigative careers in academic medicine and public health.

These grants help to defray the expense of institutions in providing the training program proposed and to enable institutions to pay subsistence stipends to predoctoral and postdoctoral individuals (trainees) in order that they may participate in the program.

By the end of fiscal year 1960 there will be about 1,700 graduate postdoctoral students in a research-training status, and for the coming fiscal year nearly $27 million will be requested for this program. These awards have had a marked effect in helping to provide stability for the basic science departments of many schools by allowing an increase of postdoctoral training opportunities and by improving the quality of the product — the trainee.

In contrast to the research-training grants, which are made to institutions, the research fellowship awards are made to individuals in order to maintain a measure of flexibility in national programming for the support of research training. The fellowships, therefore, are considered complementary to the training awards to institutions.

The fellowships serve to give students in schools of medicine, dentistry, nursing, and public

health, an orientation to and an appreciation of basic research; to allow foreign scientists to participate in the research opportunities in this country; and to provide a firm, long-range support for young academic staff members with a primary interest in research.

During the current year nearly $7 million is going into this program in seven fellowship areas: predoctoral, postdoctoral, special, part-time, postsophomore, senior, and foreign. I will touch on some of these programs, in general terms.

The predoctoral fellowships emphasize the type of general research training represented by graduate curricula and thesis requirements in the basic biological and health-related sciences. The postdoctoral fellowship makes provision for the increasingly specialized research and teaching experience of promising graduates in the years immediately following the receipt of a doctoral degree. The development and emergence of new areas in research has kindled interest in many senior, established scientists who may lack certain basic information or techniques needed to switch attention to new research fields. Special fellowships are designed to help these scientists obtain training and experience in these new areas.

The Special Fellowship Grant Program may be of particular interest to you. This Program is intended to provide advanced or specialized training which will assist in the development of a research and academic career in medicine, dentistry, public health, and related areas. It will support the young investigator not yet eligible for an award at a higher level. Individuals eligible for these Fellowships fall into three groups:

1. The person who has had at least three years of relevant research, professional experience, or both, after receipt of the doctoral degree;

2. The person who has completed the resident-training requirements in a clinical specialty or its equivalent;

3. The person who does not have a doctoral or equivalent degree but who needs special training not met by other fellowship programs.

Another area of special interest to you as orthopaedic surgeons will be the Senior Research Fellowship Program. This Program is intended to encourage and support the development of professional personnel for academic and research careers in medicine, dentistry, public health, and related scientific areas and to aid in stabilizing careers in such fields. This keenly competitive and highly regarded award program was established to provide support for academic scientists in the preclinical departments of medical and dental schools and schools of public health. Candidates who show high promise or exceptional competence are selected on the basis of their ability to establish and maintain a strong nucleus of research activity within these departments while developing themselves as well rounded academic leaders. These awards have the additional advantage of helping to relieve the critical shortage of basic investigators in the preclinical departments, as well as providing stability during a critical stage in the careers of these scientists — that is, during the period between the completion of their postdoctoral training and their eligibility for permanent senior appointments. About $3 million is currently going to support of nearly 100 Senior Fellows.

The Foreign Grants and Awards Program may be of some interest to this group. These fellowships are awarded to scientists from abroad who desire a year of advanced study and collaboration with outstanding scientists at the National Institutes of Health and at other medical research centers in this country. Since progress in medical research is made on an international basis, this award program promotes a direct and mutual exchange of ideas on technical accomplishments and scientific outlook. Candidates for these awards are proposed by a selection committee within each country, with final selection being made by the National Institutes of Health. Nearly sixty carefully selected postdoctoral fellows have been supported during 1960 at a cost of nearly half a million dollars.

Of particular interest to this group is the new Career Research Professor Program, which is intended to support professors who have demonstrated a capacity to pursue with distinction scientific careers in independent research and teaching. This program, established in 1960, will, in general, support full professors but may in exceptional circumstances be extended to associate professors. These professorships are awarded to those in full-time academic posts, with a major portion of time devoted to research. Career Research Professorship Grants are awarded initially for five years of support. Grants are provided for one year with a promise of support for the additional four years contingent upon annual appropriations, and the grants are renewable at five-year intervals unless other funds providing stable career support become available. These grants are paid to the grantee institutions for the salary of the Career Research Professor, for expenses of his research, and for indirect costs relating to the total of these two items.

The intent of this program is to establish additional full professorial positions, to assist in recruiting into these positions persons with the most thorough training and the greatest aptitude and promise for productive careers in research and teaching, and to provide still further incentive for the choice of a career devoted to research and teaching by young scholars.

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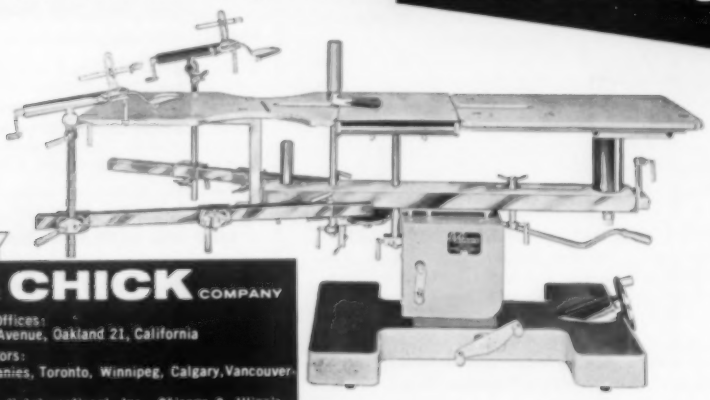

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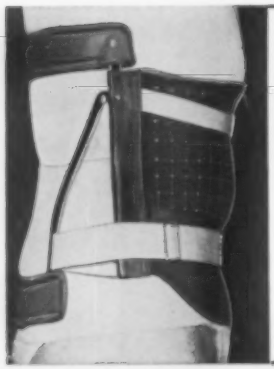

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